Environmental Consequences of Nuclear War Volume II:
Ecological and Agricultural Effects
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CHAPTER 7
Integration of Effects on Human Populations

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7.1. INTRODUCTION

The two volumes of this SCOPE–ENUWAR report constitute a synthesis of existing information estimating the types of global environmental consequences that could ensue from a large-scale nuclear war. There are many uncertainties and much research remains to be done. The biological responses to projected physical environmental perturbations cannot be detailed with precision because of: 1.) the unprecedented scale of such perturbations; 2.) the lack of an adequate empirical data base drawn from relevant experiments; 3.) the tremendous complexities that characterize biological and human systems and their interactions, especially with respect to their dynamics in response to stress; and 4.) the wide range of potential environmental disturbances being estimated by the physical scientists, associated with a wide range of nuclear war scenarios, and the continuing revision of those estimates over time. The previous chapters in this volume have described and utilized numerous methodologies and a variety of analytical approaches in evaluating the consequences of nuclear war. Clearly, no single analysis or methodology can describe the myriad of environmental responses to nuclear war; nevertheless, the combined analyses presented here portray a picture of the potential effects of a large-scale nuclear war on ecological and agricultural systems; emphasis has been placed in Parts II and III of this volume on the vulnerability of the Earth's human population to disruptions in the global food production and distribution systems. These and the other environmental consequences discussed in Part I are fundamentally important in the context of ultimate human impacts.

The previous discussions of the separate effects of nuclear war on the ecological and agricultural support bases for humans can be integrated, at least in a qualitative manner, into a discussion of potential effects on the world's surviving population. In the following sections, initial consideration is given to the projected effects on human populations from the immediate perturbations of nuclear detonations, drawing on previous analyses, especially the recent World Health Organization study (Bergstrom et al., 1984). The human casualties from the direct effects of nuclear blast, thermal radiation, and ionizing radiation are projected to be in the range of several hundred million humans, distributed primarily in the Northern mid-latitudes (WHO, 1984; Harwell, 1984; Ambio, 1982). Such population losses and the large-scale indirect perturbations such as alterations in global climatic conditions, other physical stresses, and disruptions in human support systems provide the inputs, or initial conditions, for analyses of longer-term, global environmental consequences of nuclear war.

The physical responses to nuclear war extend across a broad range of possibilities. Therefore, it is impossible for the biological analyses to operate with exactitude, even if the stress-response relationships were fully understood. Nevertheless, there is much that can be said concerning the effects on human populations if differing scenarios are systematically addressed and if the bounds of consequences on humans are identified, especially those bounds limited by physical constraints rather than determined by speculative societal and other responses. Two time frames are considered: the first year after a nuclear war, in which climatic and societal disruptions could lead to significant losses of agricultural productivity on a large spatial scale, and subsequent periods, after pre-war food supplies became largely depleted and after the climatic effects, if any, would have settled into a chronic state.

7.2 EFFECTS DURING THE INITIAL YEAR

7.2.1 Direct Effects of Nuclear Detonations

The initial consideration is of the impacts of the nuclear detonations themselves. This is an area largely outside the scope of the present analyses, and reliance is placed primarily on the recent World Health Organization study (Bergstrom et al., 1984), and analyses by Svirezhev et al. (1985), Harwell (1984), and Ambio (1982). Each of those studies considered the immediate effects of a large-scale nuclear war in which 5000 MT or more of total nuclear warhead yield were detonated over military and industrial targets, including urban areas above a certain size (typically 100,000 or 200,000 inhabitants). The specific targeting scenario varies among these and other studies, and, naturally, the immediate effects on human populations are sensitive to the specific scenario. In general, however, the range of direct human impacts is consistent among the studies, with projections on the order of several hundred million human fatalities from direct effects, i.e., from blast, thermal radiation, and fallout. As a severe case analysis, the WHO study included urban targeting on cities throughout the world that led in their calculations to total projected human fatalities of 1.1 billion. Harwell (1984) calculated that about 50%–75% of the population of the United States could succumb to the direct effects of nuclear detonations, including local fallout, and suggested that similar proportions could ensue for Europe and the U.S.S.R. These estimates are in concert with the Ambio study projections (Middleton, 1982) and others (e.g., Haaland et al., 1976; OTA, 1979). In short, the direct effects on *targeted* countries could lead to the loss of a large proportion of their populations and to the concomitant disruption or elimination of the critical social support systems in at least those countries.

Such an effect, however, would be nonhomogeneously distributed over the Earth. Combatant countries are presumed to be primarily in the Northern Hemisphere mid-latitudes, with little or no targeting in the Southern Hemisphere. The direct effects of nuclear detonations are largely quite localized with respect to blast, initial ionizing radiation, thermal radiation, and fires, as discussed in Volume I (Pittock et al., 1985). More regionally distributed would be the effects of local fallout, which would alone be responsible for virtually all of the radiation-induced fatalities from nuclear war; i.e., globally distributed fallout is not projected to reach sufficiently high levels for widespread fatalities from acute radiation exposure (Volume I). Local fallout, then, would tend to result in human fatalities within the boundaries of the targeted country, with the exception that most of Europe could be subjected to substantial doses of local fallout radiation.

The numbers of fatalities occurring during the immediate post-nuclear war period would be affected by the responses of social systems. Medical systems would be called upon on an unprecedented scale, and extreme difficulties in response could be anticipated (Abrams and Von Kaenel, 1981). The extent to which reliance could be placed on outside assistance is uncertain, and depends on geographical and societal factors, among others, which would vary enormously among locations. These considerations are outside the purview of this report, but this is clearly an area of study needing detailed exploration.

In order to identify the extent of such potential uneven distribution of immediate effects across the global landscape, an approximate calculation of the human population within broad latitudinal bands was made by assigning direct fatalities to the major and peripheral combatant countries (using estimates from WHO(1984), Harwell (1984), and Ambio (1982)) and comparing the surviving population level with the present population level (as characterized by the 1982 census data). These data are shown in Figure 7.1. It should again be emphasized that the projections of immediate casualties are rather scenario dependent; this figure illustrates the situation in response to a moderate-sized nuclear war scenario, and lesser or greater direct effects could ensue.

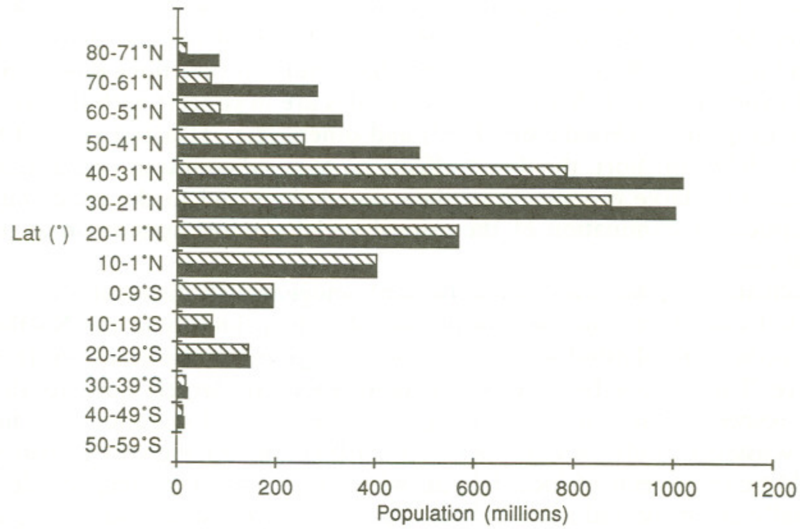

Figure 7.1 Human population distributed across latitudinal bands at current levels (solid bars) and after the direct effects of a large-scale nuclear war (striped bars) (based on calculations derived from Harwell, 1984; Ambio, 1982; and Bergstrom et al., 1983)

7.2.2 Effects on Humans of Reduced Temperatures

The possibility exists for some humans to die directly from exposure to adverse environmental conditions, particularly in tropical regions if extreme temperatures were experienced there; this is because of the general lack of adaptation to cold temperatures by humans and because of the unavailability of basic resources to protect many individuals from adverse conditions among those normally experiencing marginal human existence. However, insofar as warm clothing and fuel resources remained readily available during the period of climatic perturbations, it is not to be expected that a large proportion of the surviving population on Earth would suffer direct fatalities in response to the cold temperatures.

7.2.3 Effects from Loss of Food Imports

Indirect effects would be likely to cause much greater human impacts than exposure to cold temperatures. One area of major potential for human consequences is the effect of societal disruptions. These issues have not been the primary focus of the present study, and many such factors and their human impacts are considered to be highly speculative. Few quantitative or even qualitative evaluations of societal effects have been undertaken, yet the disruptions in economic, social order, infrastructure maintenance, and other systems offer the potential for substantial impacts. For instance, the possibility of extreme competition for limited resources, beginning in the immediate period and potentially extending far into the long term, could be expected to result in considerable impacts. It is beyond the scope of this study to evaluate such issues, but this is clearly is an area requiring concerted attention.

We can, however, separate some physical constraints on human survival that are linked to the possible disruption of societal systems. In particular, the issue of food production and exchange of food resources globally can be at least investigated with respect to the vulnerability of the current world food system.

Subsequent to the direct effects of nuclear detonations would be the effects of availability of food supplies for the surviving populations. Depending on the time of onset of a nuclear war in relation to local crop growing seasons, varying degrees of reliance would have to be placed on stored food and imports. One assumption that was used in the food availability calculations (Chapter 5) is that the export of food from countries that currently export grains would be terminated in the aftermath of a major nuclear war because of: 1.) disruptions in combatant countries, which would likely constitute the major food exporters; 2.) the likely extreme disruptions of the world economic system; and 3.) the disruption of intra- and inter-regional food distribution systems. In contrast to the assumption of termination of food exchanges between countries, it was assumed that within a country there would be an *optimal* distribution of food stores and production (i.e., equal distribution only to those who would be eventual survivors). By choosing such an assumption, which based on historical evidence from famines is clearly unrealistic for the post-nuclear war environment in combatant or non-combatant countries, evaluation can be made of the *minimum* effect that loss of food imports would entail.

To provide some perspective on the vulnerability of the current human population to loss of imports, data on grain production and imports for 135 countries of the world were examined (FAO, 1982c,d). The fraction of the total available food resources (imports plus indigenous production) that gross imports constitute was calculated on a country-by-country basis, as well as regionally and globally. The range of values is from much less than 1% to about 99%, reflecting the great divergence among countries in dependency on other countries for basic food support. A more consistent pattern emerges, however, by looking at continental scales, where the calculations show gross import fractions of 23% in Africa, 11% in Asia, 18% in South America, 20% in Europe, 13% in North America, and 12% for the world in total.

It is not simple to translate such a reduction in the food resource base to population reductions on a global scale, since many factors determine the effects of loss of imports on human support. For example, in many countries, no food imports would be needed if the current agricultural production being fed to domesticated animals were to go strictly into feeding humans directly. In another example, current agricultural production in many countries, especially in tropical regions, involves a large proportion of arable land used for export crops or non-food crops grown on typically the most productive lands, and replacement of these with food crops could reduce or alleviate the need for food importation. Further, major shifts in the consumption patterns among the surviving human population within a country could occur in a post-nuclear war environment, as changes in diet became necessary in response to differential food availability, storage capability, and other factors.

Thus, a reduction in the current level of imports that constitute, for example, the 23% of total grains in Africa might not necessarily translate into a 23% reduction in the human population of Africa, if compensatory mechanisms operated. On the other hand, the past episodes of famine illustrate vulnerability to relatively small reductions in food availability; e.g., the 1943 Bengalese famine, during which there was a loss of only about 10% of rice availability accompanied by disruptions in economic and social systems, was associated with the death of 3 million people (Sen, 1981; see Chapter 6). This example, among many others that have occurred within the historical record, indicates that there is a substantial sensitivity to the loss of small fractions of total food resources and that nonlinear societal responses can lead to disproportionate human population effects. This issue is graphically portrayed in Scrimshaw's (1984) discussion of the societal responses and feedbacks associated with historical famines, which followed perturbations of a much smaller scale than that of a major nuclear war. Further, many historical famines occurred without substantial reductions in the total food resource base.

Even though the effect of loss of imports on a global scale cannot be readily evaluated, examples for some countries can provide a suggestion of the degree of this vulnerability. Australia provides an example of a country that would have essentially no effects from the loss of imports of grains, since the fraction of its total grain imports compared to the total of grain production plus imports is less than 0.05% (and *net* imports are negative for this grain-exporting country). Loss of this level of grain inputs to the food availability system is not likely to have any noticeable effect on the Australian population. By sharp contrast, the case of Japan is a particularly instructive example of a highly sensitive country.

In Figure 7.2, 100% of indigenous production plus imports can be seen potentially to support a population that is about 150% of the current Japanese population. This increase in the support capability by 50% would occur if grains were only fed to humans and if the diet were altered to 1500 calories per person per day of grain consumption (out of a total assumed minimum requirement of 2000 cal $person^{-1}$ day^{-1}; see Chapter 5). The figure indicates, however, that loss of imports, i.e., reliance on 100% of indigenous production alone, under the same assumptions would lead to a maximum

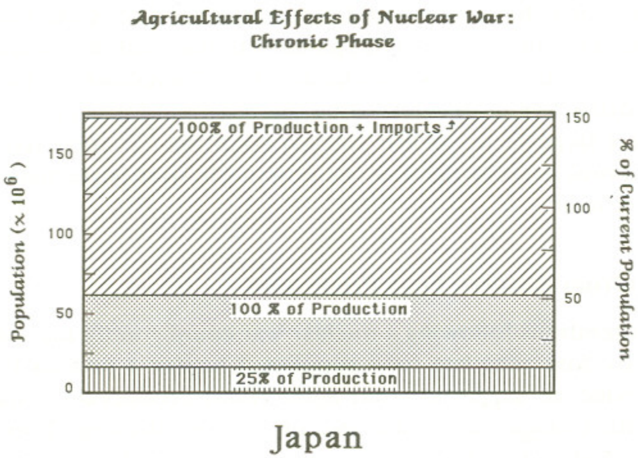

Figure 7.2 Vulnerability of Japan to reductions in food importans and food production

support for only about 50% of the current human population. This dramatically shows the extreme vulnerability in absolute terms in a region heavily dependent on imports, such as Japan, to the loss of imports. This does not consider the potential multiplying effect of societal nonlinearities under conditions of insufficient food resources. If a nuclear war did not directly impact such a region and did not indirectly involve it in exposure to climatic or other physical perturbations, loss of food imports could still lead to the death of a substantial fraction of the affected population. Either the population would have to: 1.) increase its food production markedly (an unlikely situation in the aftermath of a nuclear war, which would probably result in the loss of fossil fuel imports along with the loss of food imports, and an unlikely event in the aftermath of climatic alterations, to which Japan's rice crop is particularly sensitive); 2.) experience massive-scale exodus to other parts of the world by at least half of the Japanese population before food stores were depleted (also highly unlikely in a post-nuclear war world because of loss of transportation capabilities and unavailability of appropriate refugia for such a large number of people); or 3.) be subject to widespread fatalities associated with starvation based on the simple physical limit of insufficient quantities of food. In the latter case, the assumption of an optimal distribution pattern for the remaining food production would not likely reflect the actual situation, and even greater population losses would have to ensue.

Note, however, that the loss of food imports would not necessarily be additive to losses from other effects; thus, in the event of direct nuclear detonations on such areas as Japan, the loss of population from the immediate effects of nuclear detonations would reduce the food consumption requirements for the remaining population, perhaps to the level that loss of imports would have a greatly reduced additional effect. Nevertheless, the situation in Japan is instructive in understanding the potential for very consequential effects from a large-scale nuclear war on countries far removed from nuclear detonations, even in the absence of any physical perturbations on the global environment.

7.2.4 Effects from Reduced Food Production

Climatic alterations following a nuclear war could greatly increase the difficulty of providing adequate food supplies. Chapter 4 provided a number of lines of evidence suggesting that agricultural production is quite sensitive to climatic changes and to the loss of human subsidies. These analyses indicate that if climatic alterations occurred in which there were even brief temperature excursions near or below freezing during the growing season, there would be loss of grain crops of virtually every variety. Additionally, for many crops, most notably rice which is the mainstay of grain consumption for much of the world, brief temperature excursions down to nighttime levels of 10°C or even to 15°C (depending on the timing within the growing season) would result in loss of the crop, even though the rice plants themselves would survive. The analyses of longer periods of reduced *average* temperatures were also seen to limit agricultural crops markedly. For most crops, a 5–7°C reduction in average temperature over a growing season would limit or essentially eliminate crop yield; some crops are sensitive to as little as 1–3°C reductions. Similarly, potential reductions in precipitation were seen to lead directly to crop productivity losses. Light limitations, reduced during the chronic period by only 10%–20% below ambient normals, were estimated potentially to cause nonlinear impacts on crop productivity. The loss of human subsidies was demonstrated potentially to reduce crop productivity significantly, following similar analyses by Svirezhev et al. (1985). Global increases in ultraviolet radiation were identified as possibly resulting in crop productivity reductions, as were local incidences of air pollution, soil contamination and erosion, nutrient depletion, and many other perturbations. In short, many mechanisms have been identified, and at least in part characterized, by which a nuclear war would likely reduce the production of food.

But beyond the effects of each of these factors acting independently are the issues of interactions among perturbations. In some instances, there could be antagonistic effects, i.e., where the imposition of one stress would reduce the sensitivity to another stress. As an example, reduced temperatures can reduce the requirements for available water for the crop plant, partially offsetting the effects from the potential lowering of precipitation inputs. In far more typical situations, however, combinations of effects *increase* the impacts, and synergisms are the rule rather than the exception. These synergisms have not been adequately studied, and in large part we cannot address them quantitatively. Examples of possible synergisms are:

- Crops could have increased vulnerability to disease and pests when subject to such stresses as radiation and air pollution.
- Reduced temperatures could result in the decreased availability of insects that perform essential roles in pollination of crop plants.
- Disruptions of weather and crop information services would coincide with an increased uncertainty about the future climatic conditions to be experienced at a location.
- Societal disruptions could interfere with the optimal distribution of food among survivors.
- Societal disruptions could affect the availability of human labor for agricultural productivity.
- Overexploitation of crops and the environment, such as harvesting consumable plant parts prior to completion of the crop life cycles, could reduce long-term productivity.
- Reduced caloric and nutrient inputs in the diets of human survivors would increase the incidence and susceptibility of people to disease.
- More rapid recovery of opportunistic species of animals could enhance the vectors for disease spread to and among humans.

The list of possible synergisms extends into countless other examples. In total, the potential for such synergisms strongly suggests that the direct reduction in food producing capabilities and the direct human responses to such reductions would be worse, rather than better, than individual stress-response calculations would imply.

These considerations show that the loss of crop production within certain areas is highly likely to occur in the aftermath of a large-scale nuclear war. One key issue that remains to be adequately defined is the spatial extent of areas of lost crop productivity. This cannot be precisely characterized, because nuclear war scenarios and climatological predictions remain uncertain and may never be adequately refined to specify those areas of the Earth that would receive sufficient climatic alterations for lowered productivity. Nevertheless, the deliberations in Volume I suggest very strongly that climatic perturbations would likely be substantial and at least hemispheric—if not global—in scale. It should be clear from the discussions in the present volume that agricultural productivity is much more vulnerable than many people suppose, and that relatively small climatic alterations, or the societal effects after a large-scale nuclear war even in the absence of any climatic alterations, would each be adequate to disrupt agricultural productivity on a large scale.

The atmospheric scientists cannot tell which regions would experience subfreezing or near freezing temperatures after a nuclear war, but rather provide ranges of values that depend on uncertainties associated with the initiating nuclear war scenario as well as with the consequences of a particular scenario. In order to evaluate the potential vulnerability of the Earth to climatic and other perturbations, however, one does not have to be limited to a particular set of climatic projections. Rather, exploration can be made of what the consequences would be in absolute terms if there were *no* agricultural productivity. By making this assessment, no projection is being made that this would occur, with a particular probability; rather, the *vulnerability* of human populations to disruptions in agricultural productivity is being characterized. Such a vulnerability is manifested historically in regional areas (e.g., the sub-Sahel), but nuclear war offers the unique circumstance of imposing on a global scale the types of perturbations to which agricultural productivity is so sensitive.

7.2.5 Duration of Food Stores

If there were no agricultural productivity for the first growing season, the relevant analyses are of the amounts and duration of food stores that would exist at the time of a nuclear war and that were not destroyed directly by nuclear detonations (see Chapter 5). Such calculations provide the upper bound, i.e., the *maximum* population that could avoid starvation based on the *physical* limitations of energy requirements for human survival. That is, it was assumed that: 1.) there were total homogeneity of distribution of food stores within a country (i.e., full and equal access for all who would survive); 2.) those who would *eventually* die from starvation (i.e., the number of people in excess of the one-year food supply capacity) would do so instantaneously at the beginning of the post-nuclear war period, thereby not reducing food resources for the ultimate human survivors; and 3.) changes in dietary patterns would be made to reflect the increased reliance in general on grain calories for minimal human subsistence. Based on these assumptions, calculations can be made of the absolute upper limit of human survival under a situation of no food production for one growing season and no exchange of food across national boundaries. It should be understood that such analyses do not rely on any speculation as to human responses to a limited-food situation on the scale for an individual, a community, or a country. Rather, if one assumes no agricultural production, these calculations are the best physically limited outcome that could happen to food supplies for the human population. Other considerations of food hoarding and maldistribution, societal conflicts over limited resources, less than perfect allocation of food from the very beginning to only those who would eventually survive, vitamin and protein deficiency, increased caloric requirements in response to manual labor for food production, food spoilage and contamination, and other such factors that seem probable to ensue, but that are too speculative to characterize, would each *reduce* the number of humans that could be kept alive through the first year below the estimates provided here.

Detailed analyses constrained by these considerations were presented in Chapter 5 for 15 representative countries, along with summary analyses for 135 countries, which showed tremendous vulnerability in most countries to the loss of one year's food production. Integration across the globe can be made to provide an estimate of total human consequences. As discussed previously, the timing of the nuclear war would have a major influence on these calculations, since the stores of food on hand within a particular country vary over the annual cycle. The worst case would be represented by food stores being limited to only carryover values, i.e., if the perturbations occurred just prior to harvesting of crops when food stores were at a minimum.

Again to provide a bounding example, the effects of loss of food production for one growing season were calculated as if that were to occur when all countries had only carryover food supplies, i.e., the *minimum* stocks of food in storage. This result is presented in Figure 7.3. The extreme vulnerability of the Earth's human population to the loss of one year's food production is graphically indicated. Indeed, population levels would be reduced even below those shown because of non-food related reasons; these values, again, are *physically limited upper bounds*.

The effect of seasonality of a nuclear war on the maximum human support from extant median level food stores is illustrated in Figure 7.4. In this graph, it can be seen that much greater population support would follow the loss of food production occurring when food stocks were at their median level for each country.

Nevertheless, in comparing this figure with Figure 7.1, it becomes clear

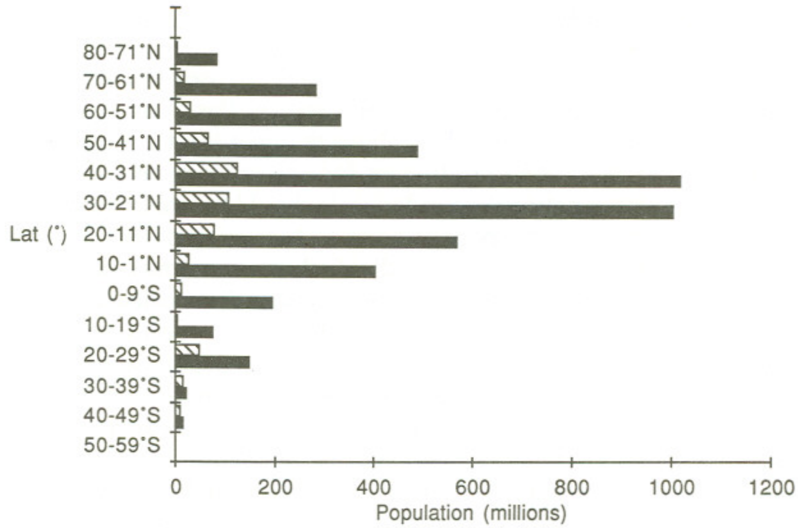

Figure 7.3 Vulnerability of human population to loss of food production if occurring when food stores are at a minimum. Current population (solid bars) and optimal number of survivors after one year (striped bars) (see discussion of assumptions in text) are shown across latitudinal bands

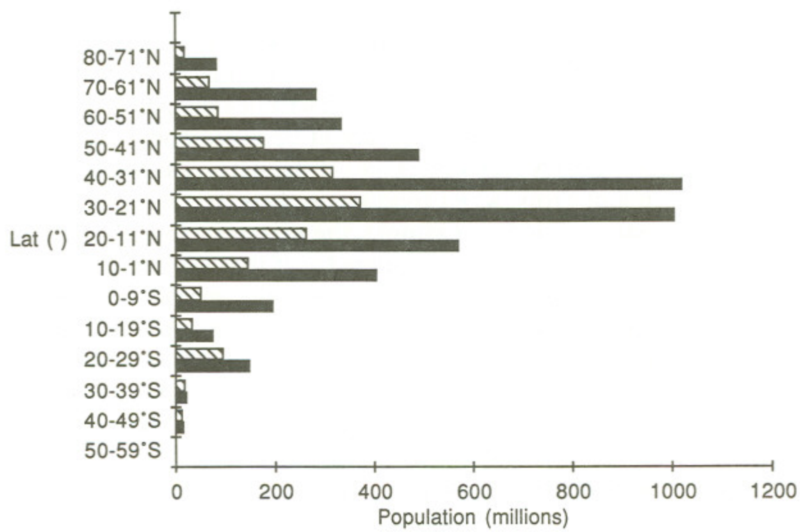

Figure 7.4 Vulnerability of human population to loss of food production if occurring when food stores are at the median level. Current population (solid bars) and optimal number of survivors after one year (striped bars) (see discussion of assumptions in text) are shown across latitudinal bands

that the human population impacts from the loss of one growing season in response to climatic and other effects of nuclear war would at a *minimum* far exceed the estimated direct effects from nuclear detonations on urban and other targets. Alternative targeting scenarios could lead to changes in the fatalities suggested in Figure 7.1, but it would be almost impossible to target nuclear weapons in order to effect direct fatalities of the magnitude and extent of potential indirect human effects shown in Figure 7.4, let alone Figure 7.3. In essence, these figures illustrate *the extreme sensitivity of human life on Earth to disruptions in the agricultural, economic, and societal bases that maintain populations far above the carrying capacity of natural ecosystems*, i.e., the levels possible without any agricultural production.

Whether or not an eventuality such as depicted in Figures 7.3 or 7.4 would actually occur would in part be determined by the spatial extent, severity, and timing of climatic perturbations, issues remaining to be resolved. That climatic perturbations sufficient to cause agricultural losses over some areas would follow a large-scale nuclear war seems quite plausible, as presented in Volume I; projections of such acute effects on a hemispheric or global scale are possible but less certain. *What can be said with assurance, however, is that the Earth's human population has a much greater vulnerability to the indirect effects of nuclear war, especially mediated through impacts on food productivity and food availability, than to the direct effects of nuclear war itself.*

7.3 EFFECTS DURING SUBSEQUENT YEARS

Many of the same issues discussed above would continue to apply in years after the first post-nuclear war year. For instance, agricultural productivity could be expected to remain reduced for long periods because of, among many factors, possible climatic alterations and their continued reverberations, continued economic and societal disruptions, lack of available energy sources, and adverse interactions with ecological systems undergoing their own reverberations. Again, it is difficult to predict quantitatively the net outcome of these and other factors acting over the long term; rather, the bounds of human population levels should be examined as determined by physical constraints associated with specific assumptions. These provide indications of the range of long-term potentialities, from which other analysts can select their own best estimates of the perturbations and derive the associated levels of human impacts.

7.3.1 Chronic Food Production Effects

One major approach to accomplishing this is to look at the situation in the post-nuclear war world at a time after food reserves from pre-war systems became largely depleted. Then the bounding calculations are of how large a human population could be maintained in a steady-state situation as a function of various levels of agricultural productivity. The same approach that was used for the detailed analyses of 15 countries for acute calculations (Chapter 5) was applied to this issue. In these analyses, the assumptions were that: 1.) there were no pre-nuclear war food stores remaining, so human support would be linked solely to extant agricultural productivity; 2.) there were no imports of food or energy resources from other countries; 3.) dietary patterns were altered to 1500 cal person^{-1} day^{-1} grain consumption out of a subsistence diet totaling 2000 cal person^{-1} day^{-1}; 4.) all grains were consumed directly by humans, rather than fed to livestock; and 5.) the maximum number of people were kept alive through perfect distribution of food at the minimally sustaining consumption rates, i.e., provided equally but *only* to those individuals who would continue to survive. These assumptions lead to an upper bound of the *maximum* number of people who could be maintained indefinitely under the physical constraints of food availability. Thus, again the important issues of societal effects, maldistribution of food, synergisms, and the many other issues discussed previously were *not* taken into account, but would tend to *reduce* the numbers of humans who could be maintained below these estimates.

Assessing the global effects of reduced long-term agricultural productivity is difficult because of differing vulnerabilities and differing perturbations that would be experienced among countries. In the assessments of the effects in individual countries, several situations were considered, as represented in Figures 5.3–5.32

1.) the effects from the loss of imports alone—This is represented by the 100% production graphic; for those countries that currently require imports to meet the food needs that would occur under the altered-consumption assumptions (e.g., Japan, Nigeria) (Figures 5.20 and 5.24), the difference between the support provided by 100% indigenous production and full population support reflects the *vulnerability* of that country to loss of imports.

2.) the effects from a limited set of human perturbations, specifically the loss of energy subsidies, energy imports, fertilizer availability, pesticide availability, etc.—This is represented by the range of production reduction levels selected based on examining the current energy dependency of the individual country with respect to agricultural productivity and the assignment of the country to a combatant or non-combatant status (i.e., whether or not it would experience direct effects of detonations).

3.) the additional effects of chronic climatic disturbances, including a few degrees of temperature reductions on average below normal, associated reductions in solar insolation, and reductions in precipitation—In the analyses, the likely range of agricultural productivity reductions associated with these physical perturbations were selected as if they were in addition to the loss of subsidies effects discussed above.

One can now look across the combined range of medium and severe chronic climatic effects, ranging from 1–5°C reductions in temperature and from 10% to 50% reductions in precipitation. The combined effect across the 15 countries was estimated by 1.) converting the fraction of population reduction associated with a particular country under particular assumptions to absolute numbers of people, 2.) summing across countries, and 3.) comparing against the current populations in those countries. The results indicate that under a scenario containing *no* climatic alterations, but with loss of imports and high energy subsidies to agriculture, from 60% to 130% of the current population of the 15 countries could be maintained indefinitely. (The apparent possibility of supporting an increased population level of 30% above the current level reflects the assumptions of altered dietary consumption, especially feeding grain production only to humans.) Thus, these summaries indicate the potential for population decreases of 0% to 40% as a result of the long-term effects of nuclear war in the 15 countries analyzed, not including potential acute or chronic climatic effects and not including the immediate fatalities from nuclear detonations. The sensitivity of these results to the specific countries selected was partially tested by performing the same analyses on a subset of these countries that did not include the U.S., Canada, and the U.S.S.R.; results were essentially unchanged, suggesting that they might be applicable to the whole global population.

One caution, however, is that the possibility of losing up to 40% of the world's population in the absence of any climatic disturbances or any immediate effects would not necessarily be additive to the losses from those effects. In particular, the reduction in the world's population by up to 20% (in the extreme case) from the immediate, direct effects of a large-scale nuclear war would reduce the food demand among the survivors. Similarly, loss of a major fraction of the world's population resulting from widespread acute-period crop failure and subsequent food stores depletion would reduce demand for food in the chronic period. On the other hand, the carryover effects into the chronic period from human losses during the first year could act to enhance the importance of long-term societal and other factors that could affect long-term human support.

Superimposing onto the effects from losses of human subsidies the ranges of effects estimated to ensue from chronic climatic conditions for the 15 countries, the combined effect is that about 30% to 80% of the population could be maintained indefinitely. Again, these calculations for the reduced set of countries (i.e., not including the U.S., Canada, and U.S.S.R.) gave essentially the same range of levels. Extrapolation to the world population would suggest a potential loss of about one to a few billion humans from long-term consequences; this wide range incorporates a wide range of differing potential environmental and societal disturbances. This calculation does *not* count the losses from direct effects or the potential losses from starvation in the first year if food supplies were depleted in response to widespread crop failures; again, these are not necessarily additive to those other effects, because the same individual cannot be killed twice, and because reduced population numbers decrease food demand. *Nevertheless, these numbers do give a sense of the extreme vulnerability of the world's human population to chronic-term effects, even if the first year's effects are not considered.*

7.3.2 Ecosystem Considerations

Chapter 3 briefly discussed the carrying capacities of natural ecological systems. The relationships between ecological productivity or other measures of ecosystem functioning and human carrying capacity are poorly understood and poorly researched. The simple calculations presented previously suggest that only a very small fraction (probably below 1%) of the current human population could be maintained indefinitely in the absence of the agricultural and societal systems that have developed over long periods of cultural evolution. This alone indicates the essential reliance on those human systems for human population support and the concomitant high vulnerability of the Earth's human population to large-scale disruption in those systems.

But it seems likely that in response to disruptions in human systems, there would be an increased reliance on natural ecological systems for human support, e.g., for food, fuel, and shelter. This increased reliance would coincide with the historically unprecedented disruptions to those ecological systems, discussed in Chapters 1–3 of this volume.

It is neither possible nor necessary to quantify how ecological disruptions would translate into a reduced carrying capacity for humans; it is enough to recognize that the *sole* reliance on ecological systems would result in almost total elimination of the current human population, and that the additional disturbance to those ecological systems would further reduce the carrying capacity to well below the 1% level. One adverse, positive feedback that could be important would be the likely overexploitation of the natural ecological systems by humans struggling for survival during the months and years after a nuclear war, retarding the recovery of those ecosystems and reducing the support they could provide humans.

7.3.3 Summary

It is apparent from these considerations of effects on agricultural, societal, and ecological systems that the *total* loss of human agricultural and societal support systems would result in the loss of almost all humans on Earth, essentially equally among combatant and non-combatant countries alike. We do not predict that such a total collapse in global systems would ensue. But it is not clear just how effective a large-scale nuclear war would be in disrupting those global systems. As the nuclear war-induced physical and societal perturbations become better characterized in future studies, and as alternate assumptions are made for stress responses, the information in the present volume can be used to evaluate the alternate impacts on humans.

7.4 FACTORS AFFECTING LONG-TERM AGRICULTURAL REDEVELOPMENT

Under any set of assumptions, there would come a point in time at which the human population would reach a minimum value and, if that level were not zero, would begin a gradual recovery. How quickly that would occur and what the recovery rates would be are not possible to estimate at this time. However, some important factors can be identified that would influence the redevelopment, or retardation of development, of the agricultural and natural ecosystem bases needed for human support. The earlier discussion of the agricultural consequences of the altered climatic variables focused on the period of the first growing season and the few years thereafter. This section identifies some of the factors that could affect the longer-term agricultural system redevelopment after the period of maximum responses to the changes in climate, the altered state of the natural biotic systems, and the human and societal inputs to agricultural productivity.

7.4.1 Physical Factors

While the extremes of global climatic disturbances are unlikely to be persistent, it is nevertheless not possible to rule out agriculturally significant climatic alterations continuing several years into the future. The effects of these types of climatic alterations were examined in the earlier discussion in Chapter 4 on the chronic effects of temperature, light, and precipitation changes on agricultural systems. Immediate survivors of a nuclear war could be faced with the prospects for long-term increases in risks of crop failure or substantial losses of crop production. These risks could result from: 1.) continued alterations in the average climatic conditions; 2.) increased frequency of occurrence of episodic events of adverse weather; and 3.) continued disruptions and insufficiencies in the availability of subsidies for agriculture.

In addition to the loss or diminution of crop productivity, longer-term climatic perturbations could exacerbate the loss of seed supplies, on which future productivity would depend. This would occur in three ways: 1.) The acute phase of the climatic disturbances could directly cause the loss of crops and the seed derived therefrom, if the acute phase occurred prior to the maturation of a crop. 2.) The chronic perturbation phase, if it occurred, would diminish the productivity of many types of crops. There would likely be a concomitant reduction in the proportion of crop production that could be set aside as seed for the next growing season, without conflicting with the immediate food needs of those dependent on that crop; this could be a particularly important factor in the event of widespread famine. 3.) Seeds planted for crops that subsequently failed, such as because of an adverse climatic episode occurring during the chronic phase, would be effectively wasted.

One of the vital inputs into successful agricultural production is the ability to predict what actions are necessary and when they would be most beneficial. These decisions involve the timing of the actions taken during the various phases of cultivation and the nature of the crop types planted in particular areas. Most of these decisions are based on an understanding, derived from experience, of what indicators to use in minimizing the risk of crop failure by choosing appropriate planting dates and seed types. The post-nuclear war situation would not allow the cultivator reasonably to rely on information from the immediate past, since the nature of the future climate would be poorly known. Further, the time lags between observations of climate and crop responses in one year and the decisions to be made in the following year would not necessarily lead to the correct decisions extrapolated from growing season to growing season, nor, for that matter, from one local area to another. Obviously, there would not likely be readily available world-scale weather information from which long-range forecasting could be made, and the value of any weather forecasting, given the nature of the potential information-isolation of regions from one another, would be minimal. Additionally, episodic climatic events of potentially large impact on agricultural productivity in a region would not be easily predictable, even in the absence of communications difficulties. For example, long-term precipitation effects might be felt locally or regionally in response to presently unknown interactions with ocean currents; as another example, local-to regional-scale climatic responses to feedbacks from devegetated areas, particularly in the tropics, could affect the hydrologic cycle.

Another physical factor affecting the longer-term productivity of agricultural systems is the extent of damage to soil productivity. Fires in both natural and cultivated areas, and the failure to protect soils during cultivation, harvesting, and periods of quiescence could result in widespread erosion (see also Svirezhev et al., 1985). This could lead to the loss of nutrients available for future crops and to a lowering of potential crop productivity. The possibility exists for local cycles of desertification which, depending on soil structure and surface winds, might feed dust into the air; such atmospheric inputs are known to affect local weather conditions. Long-term contamination of soils by radiation from local fallout and heavy metal deposition from urban fires could affect crop productivity, could reduce the areas of arable land available for safe cultivation, and could have human health effects which would vary enormously among localities. Finally, other long-term environmental perturbations could constrain restoration of full agricultural productivity; for example, the potential effects of increased UV-B from disruptions in the ozone layer (see Chapter 3).

7.4.2 Biological Factors

Physical factors alone would not determine the long-term response of agricultural systems to the stresses that could result from a nuclear war. A number of biotic inputs to agricultural production influence its degree of success. Throughout the period when agricultural systems would be subjected to some level of climatic abnormalities and in subsequent years, there would likely continue to be problems associated with interactions between agricultural and natural ecological systems. These would relate primarily to exchanges of organisms and seed sources, and to fluctuations in natural systems which could directly or indirectly affect agricultural systems.

For instance, one of the most influential factors could be the incidence of pest outbreaks (Svirezhev et al., 1985). Disruption of the industrial base for pesticide production and disruption of a distribution system which could effectively deploy remaining stores of pesticides would be expected to result in an increase in pest damage to crops, both while growing and during storage. Perturbations of natural ecosystems could influence the spread of insect and other pest species to areas of agricultural production, and continued environmental stresses could act to increase the probability that plant diseases and spoilage of stored crops would increase dramatically over those experienced before the nuclear war. Risk-reducing strategies, such as natural pest predator introduction, might be sought by those who could envision methods of combating these pest outbreaks in the absence of industrially produced chemical applications, but the uncertainties in predicting outbreaks of opportunistic species, especially in severely damaged ecological systems, would severely limit the large-scale efficacy of this approach.

The absence of an energy-intensive agricultural system would require the increased dependence on a labor-intensive and non-mechanized methodology for food production (see discussion on loss of human subsidies, Chapter 4). Draft animals would assume an increased importance in tilling, cultivating, and harvesting. Problems associated with this increased demand would include: 1.) the necessary time to replace those animals that were casualties of the conflict or were themselves food sources in the immediate post-war period; 2.) the maldistribution of the available animals among areas where there became a demand; and 3.) problems associated with the availability of breeding stocks.

Alternate planting strategies might be attempted to reduce the risks associated with agriculture in the absence of a high technological base; these could include experiments with intercropping and companion cropping (Vandermeer, 1981; Gliessman and Altieri, 1982; Horwith, 1985). Problems arise here in the areas of the adequacy of information bases on which decisions would have to be made, the distribution of this information, and the availability of seed sources.

7.4.3 Human and Social Factors

There are a number of factors potentially affecting the development of post-war agriculture that originate primarily from activities related to human and social systems decisions, as opposed to being controlled entirely by physical factors beyond the influence of individuals. In beginning the resumption of agricultural practices, it would be necessary for there to be seed sources available for planting during the first subsequent growing season. Under the pressures of possible widespread destruction of stored food sources, increased and unevenly distributed demand for food supplies for survivors, and lack of knowledge by those unfamiliar with agricultural practices, it would be possible that substantial quantities of seed sources would themselves be consumed directly as food. This, of course, would affect the extent and productivity of any planting done. For those seed sources that did survive the immediate destruction and subsequent hazards, disruption of the seed distribution system would hamper efforts to establish widespread agriculture. Additionally, those seed sources that were obtained might not be the appropriate cultivars for use at a particular location or under local weather and soil conditions. It would seem likely that, in light of possible long-term climatic alterations, there might be an increased emphasis on planting cold- and drought-hardy annuals and perennials that require relatively little processing; an important issue would be the availability of seeds for such crops that would allow such a crop-shifting strategy.

As a corollary to this, there would be an increased number of people who would be directly relying upon and initiating involvement with agricultural practices. A lack of appropriate information and an adequate base of cultural knowledge concerning agricultural practices would exacerbate an already difficult situation; regions in which largely rural populations have only recently concentrated in urban areas might fare better than older industrialized regions. For those unfamiliar with conservative agricultural practices or who attempted to rush production to provide food as quickly as possible, overexploitation of farm land could result after some time period. As the population diminished in an area, the pool of information which could lead to innovative solutions to agricultural problems might diminish (Boserup, 1965, 1983; Simon, 1983).

The widespread destruction of industrial bases could lead to a difficulty in obtaining mechanical parts for those agricultural implements that somehow remained in service through use of available energy sources. There would be some time lag between the lowering or cessation of industrial output of these parts and the initiation of severe shortages, during which time parts would likely be scavenged from local sources.

The ability to migrate to areas with increased probability of producing adequate food would be determined by many societal and physical factors, including the geography of a particular area. Populations tend to concentrate in areas with adequate rainfall for agricultural purposes; uncontaminated sources of readily available drinking water, especially along river banks; available natural resources such as energy sources; and societal resources, such as functioning technological centers and sources of medical care.

It is not unreasonable that there could arise societal conflicts, as nomadic groups came into agricultural areas and attempted to obtain food from those who were producing food in an agrarian strategy (Bronowski, 1973). At best, this interaction, with its potential for serious conflicts, could result in further disruption of agricultural efficiency and a reduction in overall distribution in the local area of production. On a much wider scale, the interactions between combatant and noncombatant areas of the world could involve issues associated with supply and demand, i.e., competition for limited resources. This might be especially evident in Northern and Southern Hemisphere interactions.

As reported in Chapters 4 and 5, widespread starvation would be the prevailing pattern for much of the world if severe climatic and/or societal disturbances resulted in loss of a substantial portion of a year's agricultural productivity. Effects of this lowering of nutritional input could carry over into the longer-term problems of agricultural redevelopment, such as relying on increased human labor by a weakened population. There would be a differential mortality across cultural and economic groups, coupled with the potential for societal conflicts associated with extreme competition for limited food that inevitably would be maldistributed. The demographic repercussions of differential mortality among age classes would play an important role in the long-term redevelopment of agricultural systems.

Psychological, medical, and sociological factors would all influence the redevelopment of post-nuclear war agriculture. These factors would be unpredictable, and they would differ across different locations in response to different climatic conditions, different nuclear war direct damage conditions, and different pre-war societal conditions.

7.5 SUMMARY

While it is not possible to make precise estimates of the total effects of nuclear war on humans or of the duration for which effects would continue to be felt, the previous discussions do provide a basis for readers to come to their own conclusions concerning the total global consequences. It seems possible that several hundred millions of humans could die from the direct effects of nuclear war. The indirect effects could result in the loss of one to several *billions* of humans. How close the latter projection would come to loss of *all* humans is problematical, but the current best estimation is that this result would not follow from the physical and societal perturbations currently projected to occur after a large-scale nuclear war.

One important issue of scale to keep in mind is the difference between estimating that on a global scale the bases for human support would be undermined for a particular fraction of the population (e.g., estimating insufficient food to support more than a certain fraction of the current population), and predicting the survival strategies of small groups of people. Projections of global-scale population losses do not mean that even in those areas in which humans would be expected to die, all would suffer the same fate. No analyses have been attempted here concerning the capability of selected humans on a relatively small scale (e.g., individual, family, community level) to find a successful strategy for survival. That a person or group in a combatant country might find a way to escape the effects of radiation, societal disruptions, climatic alterations, and the host of other potential disruptions, and still continue to survive seems possible, even in devastated areas. *That billions of people could do so in the absence of a sufficient food support base is impossible*. Thus, one needs to distinguish carefully between possible survival strategies on a small scale, and the physical limitations of support for massive numbers of people on a large scale.

In the previous discussion, predictions of specific perturbations or specific human population levels have been carefully avoided. Rather, the basis has been provided for evaluating the physical bounds that would limit human populations under differing assumptions and scenarios. It is quite clear, however, that the potential exists for climatic alterations and societal disruptions to occur on a global scale. Further, the great vulnerability of human population levels to disruptions in food support systems alone indicates that if such global-scale disruptions were to occur, then the impacts on the human populations from these indirect effects of a large-scale nuclear war would exceed in magnitude and in duration the effects from the nuclear detonations themselves.

This conclusion demonstrates that extrapolations of effects from the single nuclear detonations that occurred at the end of World War II cannot begin to characterize the reality of the world after a large-scale nuclear war. A fundamentally different picture of global suffering among peoples of non-combatant and combatant countries alike must become the new standard perception for decision-makers throughout the world if the visions portrayed in this study are to remain just intellectual exercises and not the irreversible future of humanity.

REFERENCES

Abrams, H.L., and Von Kaenel, W.E. (1981). Medical problems of survivors of nuclear war. Infection and the spread of communicable disease. *New England J. Medicine*, **305**(20), 1226–1232.

Ambio Advisory Group. (1982). Reference scenario: How a nuclear war might be fought. *Ambio*, **1**, 94–99.

Bergstrom, S., Black, D., Bochkov, N.P., Eklund, S., Kruisinga, R.J.H., Leaf, A., Obasanjo, O., Shigematsu, I., Tubiana, M., and Whittembury, G. (1983). *Effects of a Nuclear War on Health and Health Services.* Report of the International Committee of Experts in Medical Sciences and Public Health. WHO Pub. A36.12. World Health Organization Publications, Geneva: 176 pages.

Boserup, E. (1965). *The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Pressure.* Allen and Unwin Ltd., London: 124 pages.

Boserup, E. (1983). The impact of scarcity and planting on development. *J. Interdis. Hist.*, **14**, 383–407.

Bronowski, J. (1973). *The Ascent of Man.* Little, Brown, and Co., Boston, Massachusetts: 448 pages.

FAO (1982c). *FAO Production Yearbook.* Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO (1982d). *FAO Trade Yearbook.* Food and Agriculture Organization of the United Nations, Rome, Italy.

Gliessman, S.J., and Altieri, M. (1982). Polyculture cropping has advantages. *Calif. Agric.*, **36**, 14–16.

Haaland, C.M., Chester, C.V., and Wigner, E.P. (1976). *Survival of the Relocated Population of the U.S. after a Nuclear Attack.* ORNL-5041. U.S. Civil Defense Preparedness Agency, Washington, D.C.

Harwell, M.A. (1984). *Nuclear Winter: The Human and Environmental Consequences of Nuclear War.* Springer-Verlag, New York: 179 pages.

Horwith, B. (1985). A role for intercropping in modern agriculture. *BioScience*, **35**, 286–291.

Middleton, H. (1982). Epidemiology: The future is sickness and death. *Ambio*, **11**, 100–105.

OTA. (1979). *The Effects of Nuclear War.* U.S. Congress, Office of Technology Assessment, Washington, D.C.: 151 pages.

Pittock, A.B., Ackerman, T.A., Crutzen, P., MacCracken, M., Shapiro, C., and Turco, R.P. (1985). **The Environmental Consequences of Nuclear War**. Volume I: Physical. SCOPE 28a. John Wiley & Sons, Chichester.

Scrimshaw, N.S. (1984). Food, nutrition, and nuclear war. *New England J. Medicine*, **311**(4), 272–276.

Sen, A. (1981). *Poverty and Famines: An Essay on Entitlement and Deprivation.* Clarendon Press, Oxford.

Simon, J.L. (1983). The effects of population on nutrition and economic well-being. In Rotberg, R.I., and Rabb, T.K. (Eds.). *Hunger and History.* 215-239. Cambridge University Press, Cambridge.

Svirezhev, Y.M., Alexandrov, G.A., Arkhipov, P.L., Armand, A.D., Belotelov, N.V., Denisenko, E.A., Fesenko, S.V., Krapivin, V.F., Logofet, D.O., Ovsyannikov, L.L., Pak, S.B., Pasekov, V.P., Pisarenko, N.F., Razzevaikin, V.N., Sarancha, D.A., Semenov, M.A., Shmidt, D.A., Stenchikov, G.L., Tarko, A.M., Vedjushkin, M.A., Vilkova, L.P., and Voinov, A.A. (1985). *Ecological and Demographic Consequences of Nuclear War.* Computer Center of the U.S.S.R. Academy of Sciences, Moscow: 275 pages.

Vandermeer, J.H. (1981) The interference production principle: An ecological theory for agriculture. *BioScience*, **31**, 361–364.

World Health Organization (WHO). (1984). *Effects of Nuclear War on Health and Health Services.* WHO, Geneva: 176 pages.