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# Human populations and climate: Lessons from the past and future scenarios

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**Abstract**

The world population has undergone some periods of fast acceleration (the Late Palaeolithic and Neolithic revolutions, the demographic explosion started round year 1500); compared to these episodes, periods of decline appear of much smaller magnitude (except locally, of course). A variety of recovery mechanisms have existed to limit the consequences of mortality crises. Climate fluctuations, e.g., did not stop the growth of the world population. The United Nations expect a further growth of the population from 6.5 billions today to nine billions in 2050, and a possible stabilization round 10 billions by the end of the century. These projections do not take into account possible and unforeseeable catastrophes, which might also induce some new international migrations. ***To cite this article: H. Leridon, C. R. Geoscience 340 (2008).***


**Résumé**

**Populations humaines et climat : leçons du passé et perspectives.** La population mondiale a connu des périodes de forte accélération (révolution paléolithique tardive, révolution néolithique, explosion démographique à partir du milieu du dernier millénaire), à côté desquelles les périodes de rémission semblent avoir été de beaucoup plus faible amplitude (sauf au plan local, bien sûr). Il existe en effet des mécanismes de régulation des crises de mortalité. Les aléas du climat, par exemple, n'ont pas empêché la croissance de la population mondiale. Selon les Nations unies, la population devrait passer des 6,5 milliards actuels à neuf milliards environ vers 2050 et se stabiliser vers dix milliards à la fin du siècle. Ces projections n'incluent pas l'hypothèse de catastrophes d'ampleur imprévisible, qui pourraient aussi conduire à des déplacements de population. ***Pour citer cet article : H. Leridon, C. R. Geoscience 340 (2008).***


*Keywords:* World population; Projections; Climate; Adaptation; Catastrophes

*Mots clés :* Population mondiale ; Projections ; Climat ; Adaptation ; Catastrophes

Human populations have overall resisted in the past, more or less successfully, to a number of adverse contexts or phenomena, such as climate changes. The population of the world has grown rather regularly, with periods of stagnation and some fluctuations, but probably with no period of collapse or severe decline. Of course, this does not mean that local populations never decreased or collapsed even. We will first review data available on the world population over the last 70,000 years and some possible factors at play, and look at the main projections for the next 50 or 150 years.

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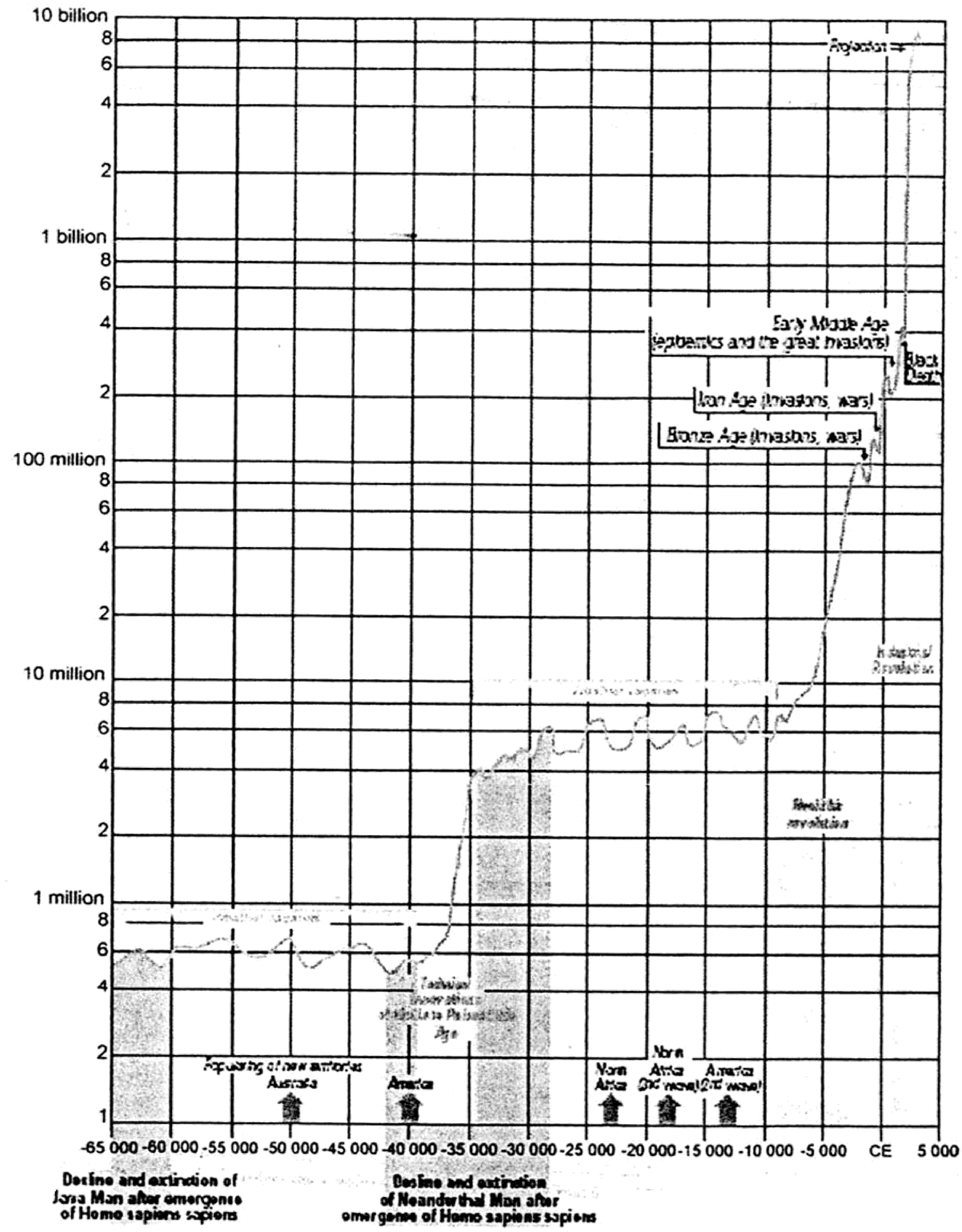



Fig. 1. The world population over the last 65,000 years, from [2].
*La population mondiale au cours des 65 000 dernières années, d'après [2].*

### *1.3. Adaptation and recovery mechanisms*

If populations are able to surmount periods of decline, this is doubtless due to a variety of mechanisms allowing for recovery. Demographers, historians and economists have suggested such possible mechanisms.

In the prehistoric ages, the main response to an external aggression was migration. Climate changes had direct effects on the nature of the soil, e.g. whether it was frozen or not, thus on the plants and animals that could live on it, and thus on the humans who depended on these plants or animals for food. Moving to the south or to the north was a rather natural decision for hunter-gatherers with no permanent settlement, as long as unpopulated spaces remained available.

In populations of the past, marital fertility was usually at its maximum and just balanced the level of mortality. 'Maximum' does not refer to a biological (and somewhat theoretical) maximum, but to a situation where fertility was not directly controlled by the couples but still limited by some behavioural and physiological parameters, such as the practice of breastfeeding. Increasing fertility after a demographic crisis was thus not possible, except under specific circumstances. But the rules of marriage could leave some room for fluctuations in the overall level of fertility. One rather well-documented case is that of prerevolutionary France (but this applies also to other western European countries, such as Italy). One striking situation of the North of France, was the great stability of settlements in terms of cities, villages and even farms between 1328 and 1713, despite episodes of Black Death and the Hundred years War [6]. Most of the land that could be cultivated was already in use, under various types of tenure, and thus almost no new settlement was possible. The dominant form of family at that time was the nuclear one, where people getting married had to quit their parental family and settle somewhere else. In practice, this means that they had to wait for a free tenancy, which occurred mostly when a tenant deceased. The level of mortality thus determined the age at marriage, which was rather high: round 27–28 years for men, and 25 years for women. If mortality suddenly increased because of some crisis (epidemic, famine, war...) then more tenancies were made available and people could marry at younger ages. Starting their reproductive life earlier, they had more children and they thus made up, at least partially, for the losses due to the crisis. This process has been quantified, for instance by Livi-Bacci [13] for Tuscany in the same period. This author has shown that a mortality increase of up to 50% over one year could be made up for. Fig. 2a shows that such crises were rather frequent during the 17th and 18th centuries: the mean interval was most often round 30 years, meaning that they were occurring at least once per generation. More severe crises, resulting in a doubling of the number of deaths during a year, were also not uncommon (Fig. 2b).

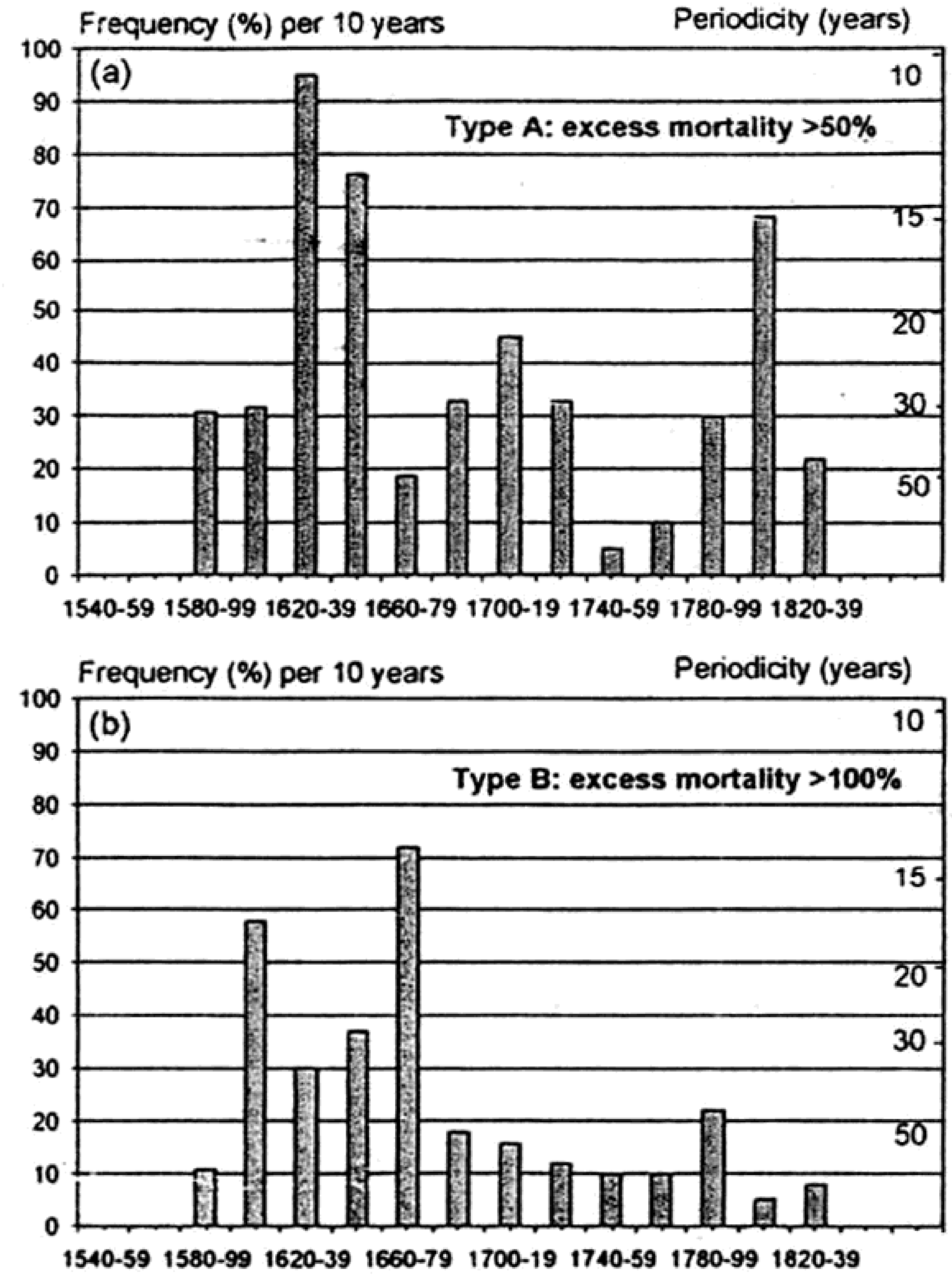



Fig. 2. (a) Frequency of demographic crises in Italy, 1560–1840: crises of Type A (excess mortality over 50%), from [13], redrawn by present author. (b) Frequency of demographic crises in Italy, 1560–1840: crises of Type B (over 100% excess mortality), from [13], redrawn by present author.

*(a) Fréquence des crises démographiques en Italie, 1560–1840 : crises de Type A (supplément de mortalité dépassant 50 %), d'après [13], redessiné par l'auteur. (b) Fréquence des crises démographiques en Italie, 1560–1840 : crises de Type B (supplément de mortalité dépassant 100 %) d'après [13], redessiné par l'auteur.*

This mechanism was based on a late age at marriage, an unusual situation in many traditional societies. In most cases it was not possible to make up rapidly for a demographic crisis. Le Bras [9], for example, has estimated that a population subjected to 75% excess mortality at age 30 years could stabilize at half its precrisis size (and later start growing again if fertility exceeded mortality). In demographic terms, a 'crisis' results from an excess of 10–20% in the number of deaths and can be surmounted, while a 'catastrophe' resulting from excess mortality of over 30% cannot.

Several (and sometimes contradictory) examples of homeostatic models have been developed, such as those linking the rate of population growth to its density (and thus to its current size), the relation being often mediated by the cost of food (crop prices) or the level of wages. A negative correlation between fertility, the main determinant of population growth when mortality is stable, and density is indeed frequently observed. Under homeostatic conditions, a reduction in population size for some external reason would ease the pressure on food and thus facilitate a new episode of demographic growth. Lee [10] has estimated that after a reduction of 20%, a population could make up for half this amount within two generations (70 years). A long era of random fluctuations is however also possible [10]. In a study on a contemporary sub-saharan population, Lutz [14] has suggested a shorter period of recovery (10–15 years) after a shock of −20% on the population size.

Climate can be entered into the picture, though experts often conclude that the impact on population

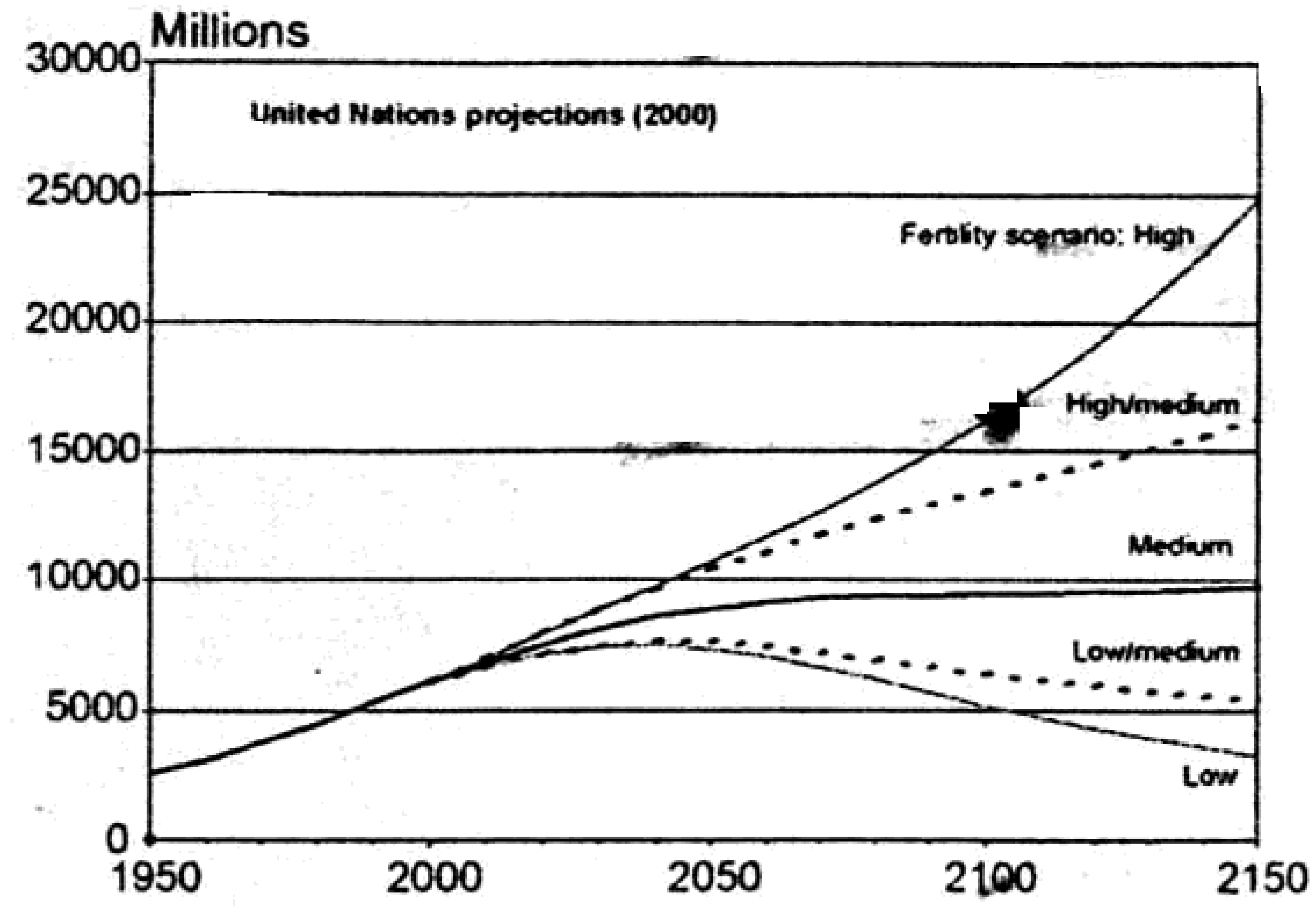



Fig. 4. Variants of the United Nations projections (2000), from [18].
*Variantes des projections des Nations unies (2000), d'après [18].*

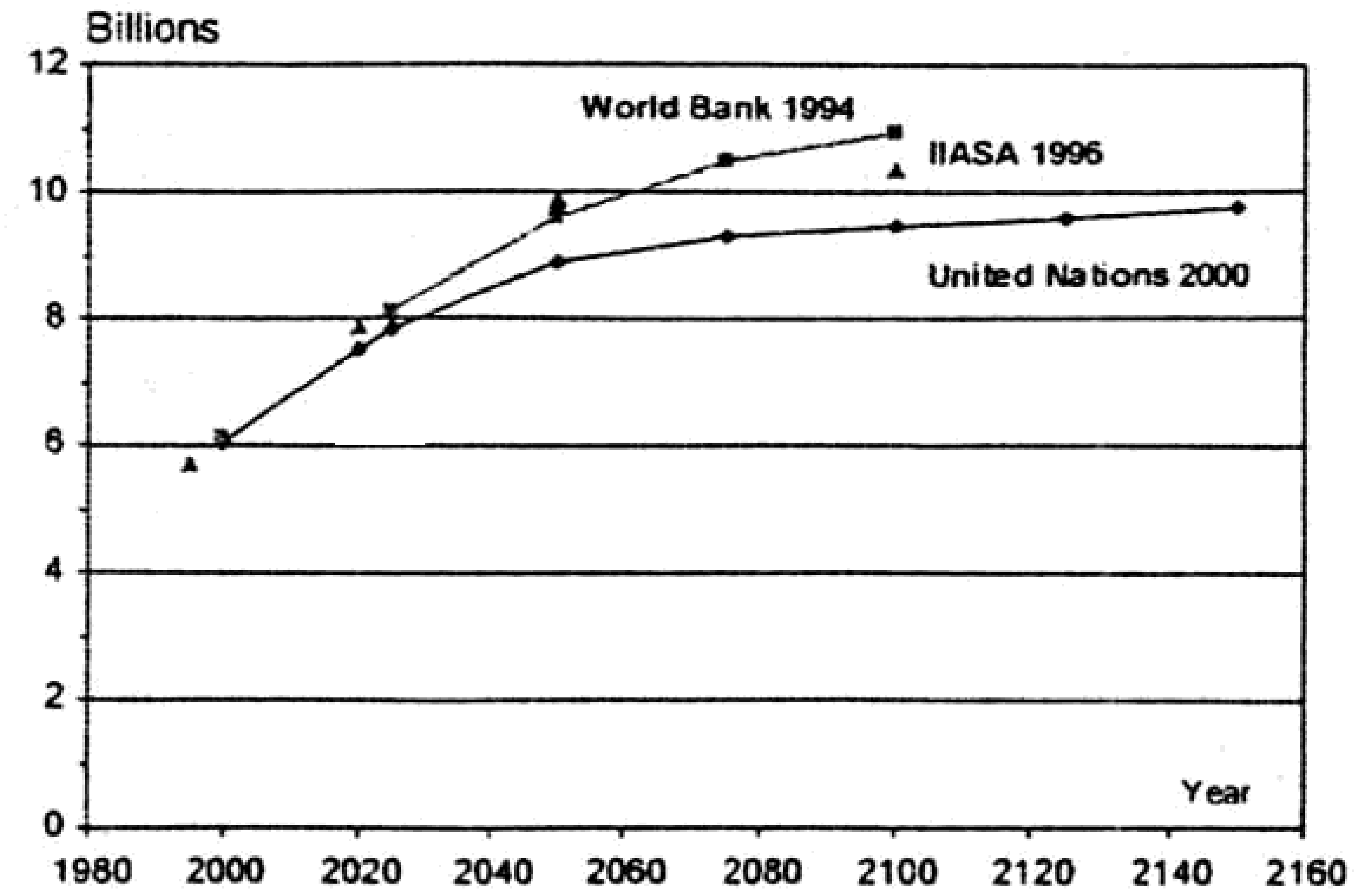



Fig. 5. Three long-term projections of the world population (medium variants), from [15,18,21].
*Trois projections à long terme de la population mondiale (variantes « médium »), d'après [15,18,21].*

nothing on any likely future: a slight error in one of the parameters has an enormous effect on the size of the population, as can be seen on Fig. 4. In this United Nations (UN) projection [18], the "high-medium" and the "low-medium" differ only by plus or minus 10% in the level of fertility to be reached in 2030 and maintained beyond (2.3 and 1.9 children per woman respectively, 10% above and 10% below the replacement level of 2.1). After 100 years, the projected world population would be twice as large in the first hypothesis as in the second one: 14.6 against 7.2 billion in year 2100; after 150 years the ratio would be close to 3.

Migrations are taken into account at the national level (the net balance is zero at the world level!), but the annual rate rarely exceeds 0.5%. The global net migration rate circa year 2000, for all more developed regions, was 0.2%; the net rate was minus 0.05% for less developed regions. According to the UN scenarios, the rates will be even lower in 2040–2050.

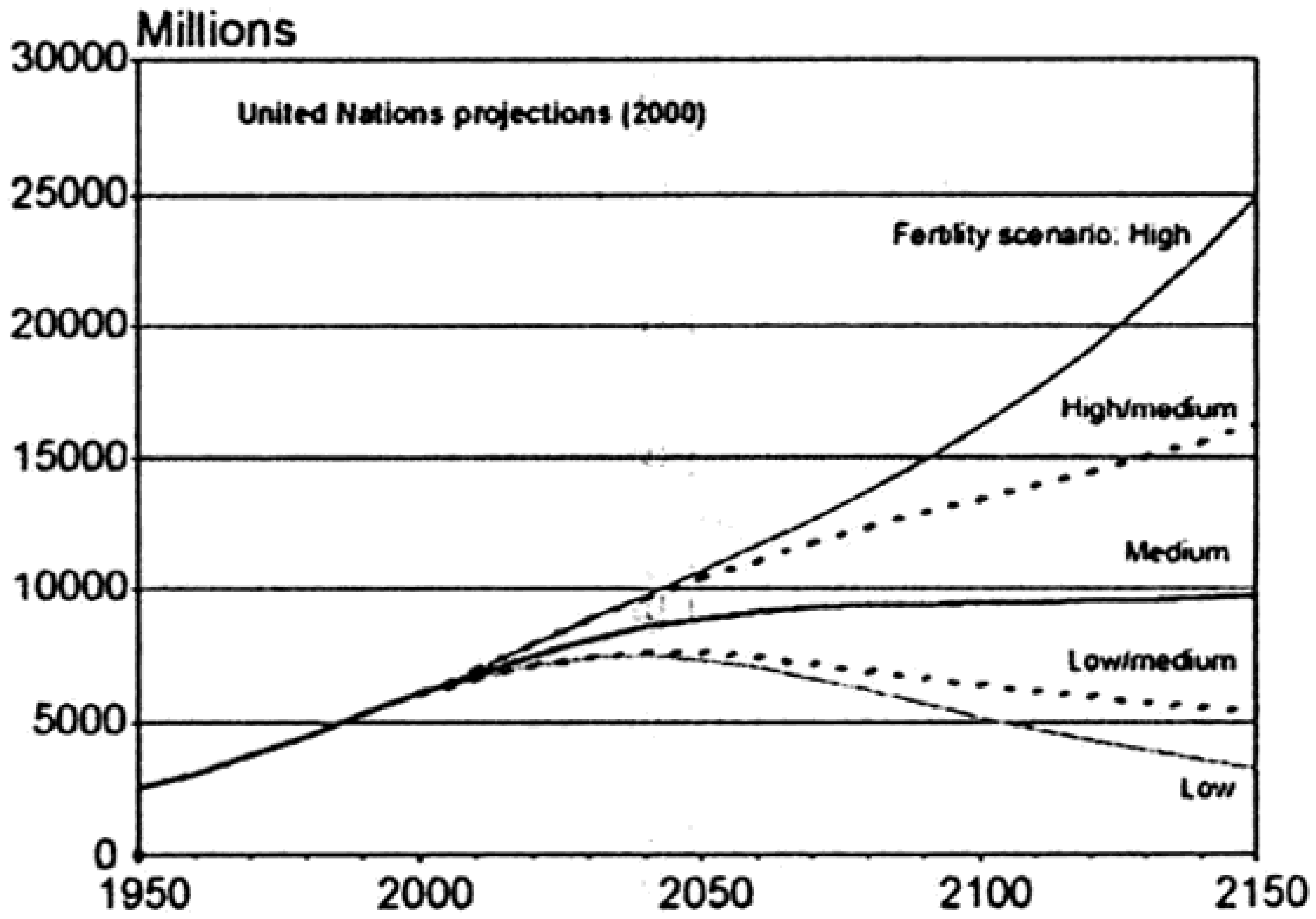
### *2.1. 2050–2100: stabilization of the world population?*

Various scenarios are usually explored in population projections. They differ mainly by the assumption made on the speed of change for fertility. In the past, the actual trend in world population came pretty close to the 'medium' scenario of the UN projections or somewhere between this scenario and the immediately lower scenario. It is now forecasted, still under the medium scenario, that the population should reach a maximum around 2075 (9.2 billion) and decline slowly thereafter [19].

Other institutions have made their own projections. They are all based on the same data and use the same methodology; they differ only by the speed of decrease for fertility. Fig. 5 shows the central projections performed by the World Bank in 1994, the International Institute for Applied Systems Analysis [15] and the UN in 2000 (base 1998). For year 2100, the projected population is respectively 10.96, 10.35 and 9.46 billions. The IIASA projection includes an attempt to estimate "confidence intervals" for the projections, based on the assumptions of experts. Each expert defines certain fractiles (e.g. upper and lower five percent) within a chosen form of statistical distribution for the projection of a given population at a given date. The combination of these subjective probability distributions forms a global probability distribution. The subjective and independent character of the approach of the various experts is not really compatible with sound statistical methodology and will certainly disqualify the study for many statisticians. If we look at the results, however, the 95% confidence interval for the 2100 projection is 6–17 billion and the 60% interval is 9–12.5 billion. It is the same order of magnitude as the difference between the UN 'high and medium' hypotheses and 'high/medium and low/medium' hypotheses.

### *2.2. Projecting catastrophes?*

All the above-mentioned projections assume rather smooth changes in the key parameters, including mortality. No major crisis is taken into account, with the sole exception of AIDS, especially in African countries. In a few countries the effect of AIDS on mortality is devastating: in Zimbabwe, life expectancy has fallen from 62 years in 1985–1990 to 40 years in 2000–2005; in South Africa, life expectancy declined

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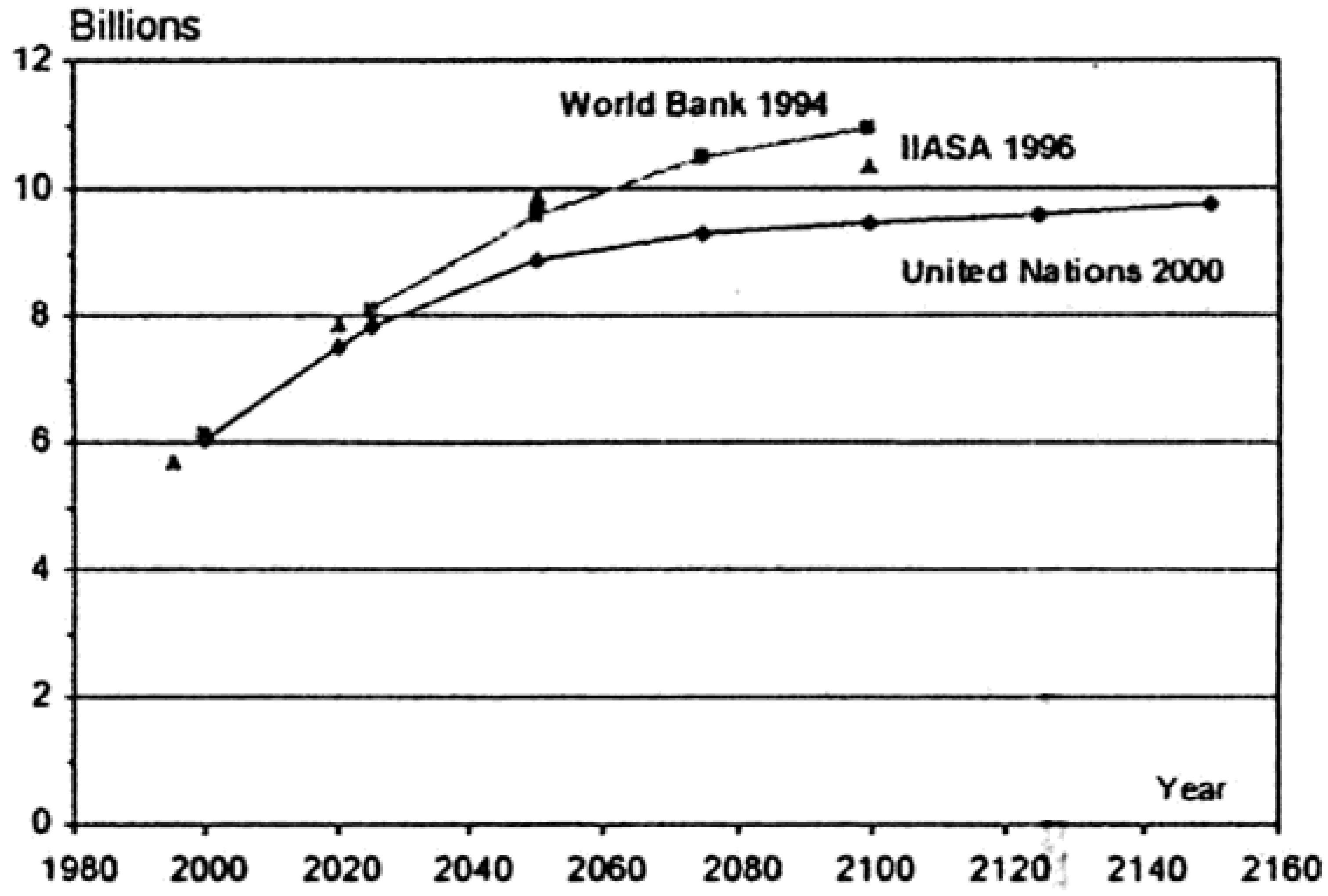


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We have already quoted above an IIASA study [14] where a severe crisis occurring in an African country is simulated. In this simulation, a natural event kills 20% of the population of the country within a few years. The precrisis size of the population is reached again within 10–15 years, because fertility is still much higher than the 'ordinary' mortality level.

A less severe example of a climatic accident was observed in France in 2003. A heat wave killed 15,000 people, the number of deaths being increased by 250% during three days, 36% during one month and 3% over one year. The immediate death toll was quite visible: hospitals and funeral homes were overwhelmed for several weeks. Lessons were learnt from this bitter experience and a much better care has been taken of the elderly, who were the main victims of the heat wave. After a small decline in 2003, the life expectancy resumed its rise with a net benefit of 0.25 years after the crisis!

It is nonetheless still possible that more severe climatic events will have more catastrophic effects on population. We just have no way of estimating them at the moment.

## References

[1] P. Acot, Histoire du climat, Perrin, Paris, 2003.
[2] J.-N. Biraben, The rising numbers of mankind, Popul. Soc. 394 (2003) http://www.ined.fr/fichier/t_publication/534/publi_pdf2_pop_and_soc_english_394.pdf.
[3] E. Boserup, The conditions of agricultural growth: the economics of agrarian change under population pressure, G. Allen & Unwin, London, 1965.
[4] M. Cartier, La population de la Chine au fil des siècles. in : I. Attané (sous la dir.), La Chine au seuil du XXI^e siècle : questions de population, questions de société. Ined (cahier n° 148), 2002, Paris.
[5] R.C. Cook, How many people have ever lived on earth? Popul. Bull. 18 (1962) 1–19.
[6] J. Dupâquier, De l'animal à l'homme le mécanisme autorégulateur des populations traditionnelles, Rev. Inst. Sociol. (2) (1972) 177–211.
[7] J.D. Durand, Historical Estimates of World Population: an Evaluation, Analytical and Technical Reports, Philadelphia Univ. of Pennsylvania, Population Studies Center n° 10, 1974.
[8] P.R. Galloway, Longterm fluctuations in climate and population in the preindustrial era, Popul. Dev. Rev. 12 (1) (1986) 1–24.
[9] H. Le Bras, Retour d'une population à l'état stable après une « catastrophe », Population 24 (5) (1969) 861–896.
[10] R. Lee, Population dynamics of humans and other animals, Demography 24 (4) (1987) 443–465.
[11] H. Leridon, Six milliards... et après ? Popul. Soc. 352 (1999) 1–4.
[12] E. Le Roy Ladurie, Histoire du climat depuis l'an mil, Flammarion, Paris, 1967 et 1983.
[13] M. Livi-Bacci, La société italienne devant les crises de mortalité. Università di Firenze, Dipartimento di Statistica (Conférences au Collège de France), 1978.
[14] W. Lutz, Population-Development-Environment: Understanding their Interactions in Mauritius, Springer-Verlag, Berlin, 1994.
[15] W. Lutz, The Future Population of the World: What Can We Assume, Earthscan (IIASA), London, 1996.
[16] B. O'Neill, F.L. MacKellar, W. Lutz, Population and Climate Change, Cambridge University Press, Cambridge and IIASA, 2001.
[17] G. Pison, Will AIDS lead to a population decline in Sub-Saharan Africa? Population and Societies n° 385, 2006. (http://www.ined.fr/fichier/t_publication/499/publi_pdf2_pop_and_soc_english_385.pdf).
[18] United Nations Population Division World Population Projections to 2150. New-York: United Nations, 2000.
[19] United Nations Population Division World Population Prospects: the 2004 Revision. New-York: United Nations, 2006.
[20] United Nations Population Division. World Population Prospects: the 2006 Revision. Extended CD-ROM Edition. New-York: United Nations, 2007.
[21] World Bank. World Population Projections, 1994–1995. The Johns Hopkins Univ. Press Baltimore, 1994.