Week 10 – Lecture # 1

Geology – The Human Perspective

Press & Siever chs. 22 – 23

Judson & Richardson Transition 4
Chapters 19 & 20 — three themes:

new edition chs 22, 23 and 14 (glacial cycles)

(1) Availability of resources: minerals & energy

(2) Impact of humans on the environment – global change, pollution

(3) Impact of the environment on humans – geological hazards (earthquakes, volcanoes, floods, storms, etc.)

Natural place to ~~[illegible]~~ begin – population growth

Excellent reference: How Many People Can the Earth Support, Joel E. Cohen (1995)

skip to page 2 first

Population Growth Equation:

N_t = number of people living on Earth at ~~[illegible]~~ in year t.

$$\boxed{N_{t+1} = N_t + B_t - D_t}$$

B_t: no. of births in year t

D_t: no. of deaths in year t

Suppose that

$$B_t = b\, N_t \quad , \quad D_t = d\, N_t$$

b ↑ birth rate (no. of births per capita per yr)

d ↑ death rate

$$N_{t+1} = (1 + b - d)\, N_t = (1+r)\, N_t$$

where $r = b - d$ is the population growth rate

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skip → to here

Wait — better to start with compound interest. Everyone understands this.

Suppose you deposit \$1000 in a bank on the day you are born.

Suppose the bank pays 5% interest

On your first birthday you have:

$$\$\,(1.05)\,1000 = \$\,1050$$

On your second:

$$\$\,(1.05)\,1050 = (1.05)^2\,1000 = \$\,1103$$

On your eighteenth birthday, when you enter Princeton:

$(1.05)^{18} \, 1000 = \$ \, 2407$ ← enough to buy your freshman books at the U-store

Not enough to pay your tuition, but much better than when you started.

When you die, at age 75,

$(1.05)^{75} \, 1000 = \$ \, 38{,}833$

↑ you can give it to your grandson or granddaughter for spending \$ in their first year at Princeton

The general formula is:

$$\boxed{\$_t = (1+r)^t \, \$_0}$$

An example of exponential growth, so-called because the time t appears in the exponent

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Now, back to population

$$\boxed{\begin{aligned} N_{t+1} &= (1+r) \, N_t \\ N_t &= (1+r)^t N_0 \quad \text{where } r = b - d \end{aligned}}$$

Banker's notation: $N_t = N_0 \, (1+r)^t$

A scientist or demographer would write this in the form

$$N_t = N_0\, e^{[\ln(1+r)]t} = N_0\, e^{t \ln(1+r)}$$

The scientist's exponential growth rate is

$$\lambda = \ln(1+r)$$

$$N_t = N_0\, e^{\lambda t} \leftarrow$$ the opposite of exponential decay already encountered in this course

For small growth rates $(r \ll 1)$

$$\lambda = \ln(1+r) \approx r$$

For example

$$\ln(1.05) = \underset{\uparrow\ \text{scientist's rate}}{0.04879} \approx \underset{\uparrow\ \text{banker's rate}}{0.05}$$

Let us stick with scientist's notation

$$\boxed{N_t = N_0\, e^{\lambda t}}$$

The growth rate λ is the slope on a ~~log~~ semi-log plot:

$$\boxed{\ln N_t = \ln N_0 + rt}$$

Growth rate and doubling time

Given r or λ, what is the doubling time of the population (analogous to the half-life)?

$$N_t = N_0 e^{\lambda t} = 2N_0$$

$$e^{\lambda t} = 2$$

$$\lambda t = \ln 2$$

$$t = \frac{\ln 2}{\lambda}$$

$$\boxed{t_{doubling} = \frac{\ln 2}{\lambda}} \boxed{= \frac{0.693}{\lambda}}$$

$$\boxed{\ln N_t = \ln N_0 + \lambda t}$$

Let's look at some data — number of people N_t on $\oplus$ as a function of time t.

see Nov '96 NYT article

Homo ~~[illegible]~~ emerged as a separate genus species between 1 and 4 m.y. ago and spread out from the rift valley of Africa to the entire world.

Obviously, our estimates of N_t become more uncertain as we go back in time.

First, the geological perspective — back 1 million years.
Essentially no people at all for the first 998,000 years, then dramatic growth during the past 2000 years.

Current world population 5.7 billion call this ~ 6 billion

How to visualize this?

use this

Continental land area on Earth: including Antarctica

non-ice covered land $1.3 \cdot 10^{14}$ m^2

$$1.6 \cdot 10^{14} \text{ m}^2 = 1.6 \cdot 10^{8} \text{ km}^2$$

If people were spread out uniformly over continents, each one would have

non-ice covered area
$1.3 \cdot 10^8$ km^2 $\Rightarrow$ 2 ha

45 people / km^2 of ice-free land

45 people per km^2

2 ha $\approx$ 4 football fields

1 hectare
100 m × 100 m
≈ two football fields

Take a closer look — past 12,000 years

Almost all growth in past 200 years

And now, going back only 2000 years (birth of christ) at which time there were about 250 million people

Passed 1 billion in about 1800 — only 200 years ago.

What is average growth rate of population in past 2000 years?

$$r = 0.00159 \quad (\text{or } 0.159\ \%)$$

$$(250 \cdot 10^6)(1.00159)^{2000} = 6 \text{ billion}$$

mean doubling time
t_{double} = 440 years

Compare with actual curve — much different. Why? Rate of growth is changing with time. Much slower than average in the past, much faster than average at the present time.

Now must solve:

$$\boxed{N_{t+1} = (1+ \underset{\substack{\uparrow\\ \text{time-dependent rate}}}{r_t}) N_t}$$

Solution is:

$$N_t = \underbrace{(1+r_0)(1+r_1)\cdots(1+r_{t-1})}_{\substack{\text{product of}\\ t \text{ terms}}} N_0$$

Take logarithm:

$$\ln N_t = \ln(1+r_0) + \ln(1+r_1) + \cdots \ln(1+r_{t-1}) + \ln N_0$$

$$\ln(N_t/N_0) = \lambda_0 + \lambda_1 + \cdots \lambda_{t-1}$$

where $\lambda_t = \ln(1+r_t)$

$$\boxed{\begin{aligned} N_t &= N_0\, e^{\sum_{t'<t} \lambda_{t'}} \\ &= N_0\, e^{\lambda_0 + \lambda_1 + \cdots \lambda_{t-1}} \end{aligned}}$$ — generalized exponential growth

If all the λ_t are the same: $\lambda_t = \lambda$

Then $\lambda_0 + \lambda_1 + \cdots + \lambda_{t-1} = t\lambda$ and $N = N_0 e^{\lambda t}$

as before.

What is the total number of people that have ever lived upon the Earth?

It is not

$$N_{cum} \neq \sum_t N_t$$

since many of the people living in year t were also living in year $t-1$.

Rather, it is

$$\boxed{N_{cum} = \sum_t N_t / T_t}$$

where T_t is the life expectancy of the average person at time t.

Ronald Lee, a demographer-economist at UC Berkeley, estimates that

$$\boxed{N_{cum} \approx 110 \text{ billion}}$$

Thus 5% of all the people that have ever lived upon the ⊕ are alive today.

Not With a Whimper but a Ba

Doomsday may be near; the villains include green scum, gray goo and S

THE WORLD
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percent. It is nowhere near 10 percent. Ronald Lee, a demographer and economist at the University of California, Berkeley, says the accumulative population is projected to be 110 billion in the year 2000, with 6 billion of them, or 5.45 percent, still living. Now, the first two humans were 100 percent of the total. Even a few generations later, more than 50 percent must have been alive. So that 5.45 percent looks pretty good. But why does this matter? Mr. Leslie says it is more logical to assume we are in the very last 10 percent of humans rather than, say, in the first 0.01 percent; therefore, statistically, we are doomed.

It's possible that much of "The End of the World" is tongue in cheek. Mr. Leslie's prose, untranslated from the original Canadian, is sometimes as hard to decipher as his math. There are endless exercises in logic. Which is not to say that "The End of the World" isn't a fun read. But Mr. Leslie never really tells us where he's coming from, though

resolution to our story. We're not Hindus, with eight-billion-year recurrin cycles. We like our universe built in se en days, and we expect apocalyps demand.

A less expansive but more or book is "Why Things Bite Back point made by Edward Tenner. an with a Hopi attitude, is n that the world is going to technology simply allows our own *koyaanisqatsi* fa threatened not with ca with subtle reciprocal ef calls "revenge effects." when X-rays were intr 1890's, they became a sc ple with foreign objects bodies, even those who from them, now asked tracted — a procedure had fatal complications." gists herald the use of che sants to break up oil sp are saved, but the pet

Cohen recognizes four ~~[illegible]~~ evolutions or stages in human population growth, each associated with major changes in the growth rate

Stage 1 — invention of agriculture

8000 – 4000 b.c.

increased the doubling time by a factor of ~100

Stage 2 — globalization of agriculture
addition of new world foods to diet (in Europe — quickly spread to Asia)

1650 – 1850

doubling time increased by another factor of ~10

exact cause unknown — improvements in nutrition — lowering of infant mortality rate

Stage 3 — public health revolution
1945 – now

post WW II significant increase in life expectancy

e.g. eradication of smallpox

factor of 3–4 increase in growth rate

Note ~~decline~~ decline in world population in 14th century.

This a consequence of the plague or "Black Death" which killed ~1/3 of all people living between India & Iceland

For an excellent account see A Distant Mirror by Barbara Tuchman (1978)

Stage 4 — the fertility evolution 1970

Growth rate λ_t declined from its all time high of 2.1% per year due to many complex factors

Current growth rate is

$$\boxed{\begin{array}{ll} \lambda_{now} = 0.016 & (1.6\%) \\ T_{double} = 43 \text{ years} & \end{array}}$$

$\lambda_{now} N_{now} = 100$ million new people each year ($\frac{1}{3}$ population of US)

more than 6 billion in year 2000

~~Talk about cumulative number~~

To dramatize the magnitude of the "population problem" one can project the current rate into the future.

How long, at current rate, until $\exists$ one person on every m^2 of land area

$$1.4 \cdot 10^{14} = 5.7 \cdot 10^9 \, e^{0.016 t}$$

$$N_t = N_0 \, e^{\lambda t}$$

if use 1.3 (exclude Greenland & Antarctica)

$$t = \frac{1}{0.016} \ln \left(\frac{\cancel{1.4}\ 1.3 \cdot 10^{14}}{6\ \cancel{5.7} \cdot 10^9} \right)$$

$$= \underline{640 \text{ years}} \qquad \underline{600 \text{ years}}$$

use this example

How long until world's people comprise a solid sphere of flesh with volume same as that of the Earth?

assume $\rho_{flesh} = \rho_{H_2O}$

$$\frac{\frac{4}{3}\pi (6.4 \cdot 10^6)^3 \cdot 1000 \text{ kg/m}^3}{60 \text{ kg}}$$

average person's weight

$$= 1.8 \cdot 10^{22} \text{ people}$$

$$1.8 \cdot 10^{22} = 6 \cdot 10^9 (1.016)^t$$

$t = \underline{1800 \text{ years}}$ — less than the time since the birth of Christ, when there were only 250 million people.

Birth and death rates

The low growth rates in the 18th & 19th centuries were the difference of two large numbers

$$r_t = b_t - d_t$$

b_t ↑ lots of children per family

d_t ↑ high infant mortality rates

e.g. Thomas Jefferson & wife Martha had six kids, only two survived childhood, only one lived past 26.

At the present time

$$r_t = b_t - d_t$$

$$1.6\% = 2.6\% - 1.0\%$$

Improvements in public health can also be measured in terms of increase in average life expectancy

T_t = life ~~expectancy~~ expectancy

Currently:

	women	men	average
developed	78 years	71 yrs	75 yrs
less developed	64 yrs	61 yrs	62 yrs
sub-Sahara Africa	55 yrs	52 yrs	53 yrs
world average	67 yrs	63 yrs	65 yrs

Fertility revolution — falling birth rates — now a worldwide phenomenon except in sub-Sahara ~~Africa~~ Africa

Population evolution in developing countries ~~[illegible]~~ similar to that in developed countries, with a time lag of about 150 years.

Birth rates can also be expressed as ~~[illegible]~~ average number of babies born to a woman in her lifetime

actually, this should be $1+\frac{63}{67} = 1.9$ ~~[illegible]~~ because there are more women (see page 11½)

$$\frac{\#\text{ babies}}{\text{woman}} = b_t \cdot \cancel{2}\ 1.9 \cdot \text{life expectancy for women}$$

$$\left(\frac{\text{births}}{\text{person-yr}}\right)\left(\frac{\text{persons}}{\text{woman}}\right)\left(\frac{\text{yrs}}{\text{lifetime}}\right)$$

$$= (0.026)(\cancel{2}\ 1.9)(\cancel{65}\ 67)$$

$$= 3.3\ \frac{\text{babies}}{\text{woman}}$$

note: $\left(1+\frac{63}{67}\right)\cdot 67$ is same as $2\cdot 65$
$\frac{1}{2}(63+67)$
world-wide average

Men versus women:

Assume two separate steady-state populations:

N_1 = women T_1 : life expectancy
N_2 = men T_2 : life expectancy

Say $B_1 = B_2$ (equal numbers of men and women born each year — this must be very nearly true)

Steady-state: $b_1 = d_1 = 1/T_1$

$b_2 = d_2 = 1/T_2$

Then $N_1 = B_1 T_1$ $N_2 = B_2 T_2$

$$\boxed{\frac{N_{women}}{N_{men}} = \frac{T_{women}}{T_{men}} = \frac{67}{63}}$$

There should be, according to this argument, about 6% more women than men in the population — because they live longer.

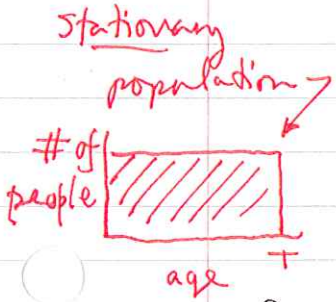
Is this true? yes! Note that total number of babies/woman is

$$\# \text{babies/woman} = \frac{B_1 T_1 + B_2 T_2}{N_1} = \frac{N_1 + N_2}{N_1} = 1 + \frac{N_2}{N_1} = 1 + \frac{T_1}{T_2}$$

Zero population growth requires

$$\boxed{b_d = d_t \quad (r_t = 0)}$$

In a stationary steady-state population
(one with equal numbers
of people in each age bin)
it is easy to see that



$$\boxed{b = d = \frac{1}{T \leftarrow \text{life expectancy}}}$$

This is just the residence time equ
we have encountered before in
this course

$$\underset{\substack{\text{residence time}\\ \text{of a person in}\\ \text{population pool}}}{} \rightarrow T = \frac{N \;\leftarrow \text{total population}}{B \;\leftarrow \text{no. of people born per year}} = \frac{1}{b}$$

The ZPG birth rate is not simply
2 babies / mother because the
life expectancies of men are less
than women — men are defective —
must produce more

$$1 + \frac{67}{63} = \underline{2.06 \text{ babies / mother for ZPG}}$$

Less than that in many developed countries.

Average in developed countries: 1.9
China 2.5
Average in developing countries 3.6

<u>Projection</u> of current rates is fraught with uncertainty.

First, a cautionary tale:

Before WW II, many projections by demographers of US population.

Ranged from — plateau at 150 million to peak at 140 million (in ~1970) followed by decline.

Actual population currently ~ <u>270 million</u>

Projections failed to predict the baby boom — postwar increase in birth rates from 1.8% during Depression to 2.4%.

John Suppe & I were born in 1942 and both got cushy jobs teaching at Princeton before the baby boomers graduated from college.

Bill Clinton was born in ~1948.

UN projections:

If the current country-by-country rates continue:

700 billion people in 2150
99.8% in less developed countries
60% in Africa
46% under age 15

13 m x 13 m square
~ the size of a
2-car garage

700 billion people ⇒ 200 m^2 per person

These projections assume that life expectancy continues to climb up to a world-wide value:

women — 87.5 yrs
men — 82.5 yrs
⟩ average 85 yrs

More hopeful predictions assumed that ZPG would be reached

$$b = d = \frac{1}{85 \text{ yrs}} = 1.2\% \text{ in steady state}$$

Even with "instant replacement" the population would climb to <u>8.4 million</u>

Why — high percentage of young in today's population (~1/3 less than 15 years old)

Question — the current birth, death and population growth rates are

$$\boxed{\begin{aligned} r_{now} &= b_{now} - d_{now} \\ 1.6\% &= 2.6\% - 1.0\% \end{aligned}}$$

For steady-state ZPG with $T = 85$ years, we must change to

$$\boxed{b_{steady\text{-}state} = d_{steady\text{-}state} = \frac{1}{T} = 1.2\%}$$

The birth rate (world-wide) must decline to 1.2% / yr (2.1 babies/woman)

And the death rate must <u>rise</u> from 1.0% to 1.2% ! What?

This is because the current population is very young — in a true steady-state population there will be equal numbers in all age brackets between 0 and 85 years.

Each of these young women will grow up and have 2.06 babies on average.

Other UN projections —

low — "stabilize" at 1.7
high — "stabilize" at 2.5
medium — "stabilize" at ~~2.06~~
(2.06)

The population in 2150 varies by a factor of 7 from the high to the low scenario.

Shows the extreme sensitivity of the projections to uncertain assumptions.

Another way to view this sensitivity — the long-term perspective.

Ten millennia ago there were

~ 6 million people

~ 5.7 million people

By the year 2000 there will be ~ 6 billion

Now there are 5.7 billion

Factor of 1000 increase in 10,000 years

Ten doublings : $2^{10} = 1024 \approx 10^3$

Average doubling time 1000 years
(recall current doubling time is $\frac{1}{25}$ of that 43 years)

If we are to survive as a species for another 10,000 years, the average growth rate cannot exceed the average over the past 10,000 years

$$\lambda = \frac{\ln 2}{1000} = 0.00069 \quad (0.069\%) \text{ per yr}$$

$2^{20} \approx 10^6$

We will look in more detail at the Earth's carrying capacity in the next lecture BUT...

Why not — would be 5.7 trillion people $\Rightarrow$ 25 m^2 per person (a 5m x 5m jail cell)

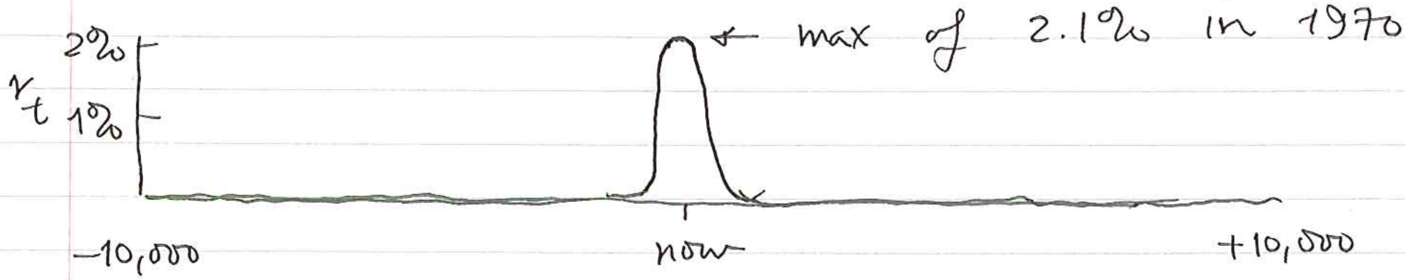
No possibility of supporting that many people (providing food, water, fuel, etc.)

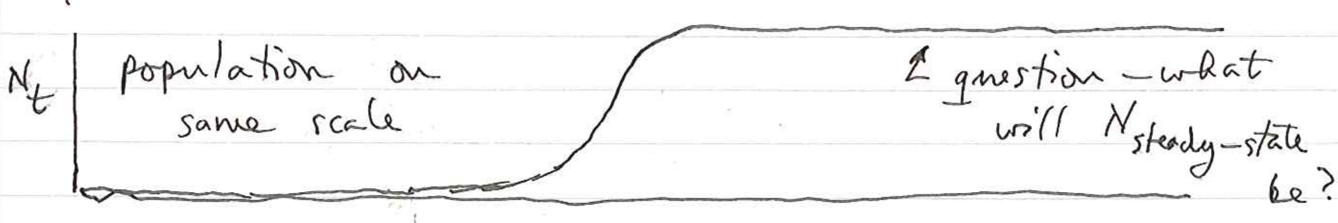
We are compelled to keep the birth and death rates equal to an extremely fine degree

$$b_t = d_t \pm 0.069\%$$

$$b_t = d_t = 1.2\% \pm 0.069\%$$

From a long-term (geological) perspective a plot of growth rate r_t versus time must look like this





The growth rate can be lowered to zero in two ways:

$$r_t = b_t - d_t$$

people choose to lower the birth rate (as has happened in developing countries)

← fertility decrease can also be imposed by governments, e.g. the one-child policy in China

OR, raise the death rate

(this reason for only $r_t < 0$ in history — The Black Death

What about AIDS?

Horrible disease — painful, wasteful — strikes people in their most productive years.

Could AIDS substantially lower r_t in populous countries?

Very difficult to answer — depends on the rate of transmission.

Opinions of experts highly variable

Different models predict very different reductions in r_t even for a given % prevalence of HIV infection in the adult population

e.g. HIV prevalence 30% $\delta r_t = 1\% - 3\%$

Current estimates: 14 million + HIV infections, ~~more than~~ 65% in sub-Sahara Africa.

1997 UN revision — 31 million with HIV or AIDS
21 million of these in sub-Sahara Africa

Finally, let me dispense with the possibility of extraterrestrial migration as a solution to the population problem

$$r_t = b_t - d_t - e_t$$

↑ extraterrestrial migration rate

To reduce r_t to zero by this means alone would require

$$e_t = 0.016 \quad (1.6\%)$$

Export of 90 million people / year

Entire population of US in 3 years.

Would bankrupt the entire planet.

Furthermore, the rest of the solar system is not very hospitable — where would they go?

Not a viable option — certainly not in the next century, when we must solve this problem.

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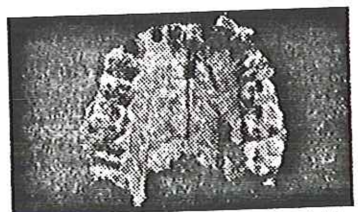
2.3-Million-Year-Old Jaw Extends Human Family

By JOHN NOBLE WILFORD

An upper jaw found in the Hadar badlands of northern Ethiopia is being hailed as the most convincing and earliest definitively dated fossil of the genus Homo, to which living humans belong.

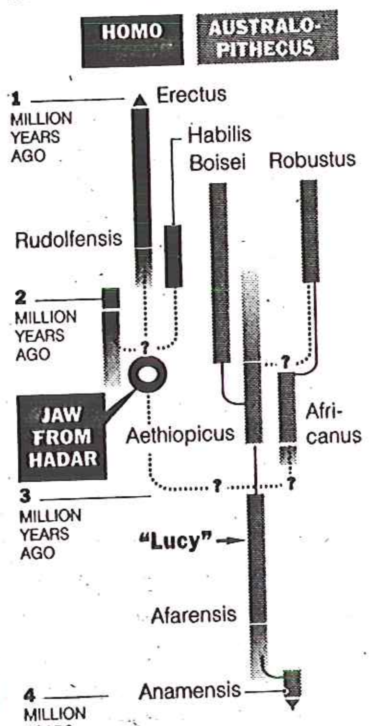
The 2.33-million-year-old jaw extends the established age of the human family line by 400,000 years, closer to the time of the first evidence of toolmaking and to environmental upheavals that may have been decisive in human evolution. The fossil was found in sediments with a scattering of crude stone tools, the earliest association between Homo remains and such artifacts.



W. Kimbel/Institute of Human Origins

Jaw from Hadar, Ethiopia.

A New Clue In Human Evolution



Source: Institute of Human Origins/ The Journal of Human Evolution

The New York Times

Of greatest potential importance, paleontologists said, is the rare glimpse the discovery provides into what has been a kind of dark age of evolutionary change, the period between three million and two million years ago. Scientists are all but certain that sometime in that epoch the genus Homo evolved from the more apelike australopithecines, yet the fossil record in Africa for that period has been frustratingly spotty.

The new discovery was announced yesterday by a team of American, Canadian, Ethiopian and Israeli scientists. A detailed description and interpretation of the fossil is being published in the December issue of The Journal of Human Evolution.

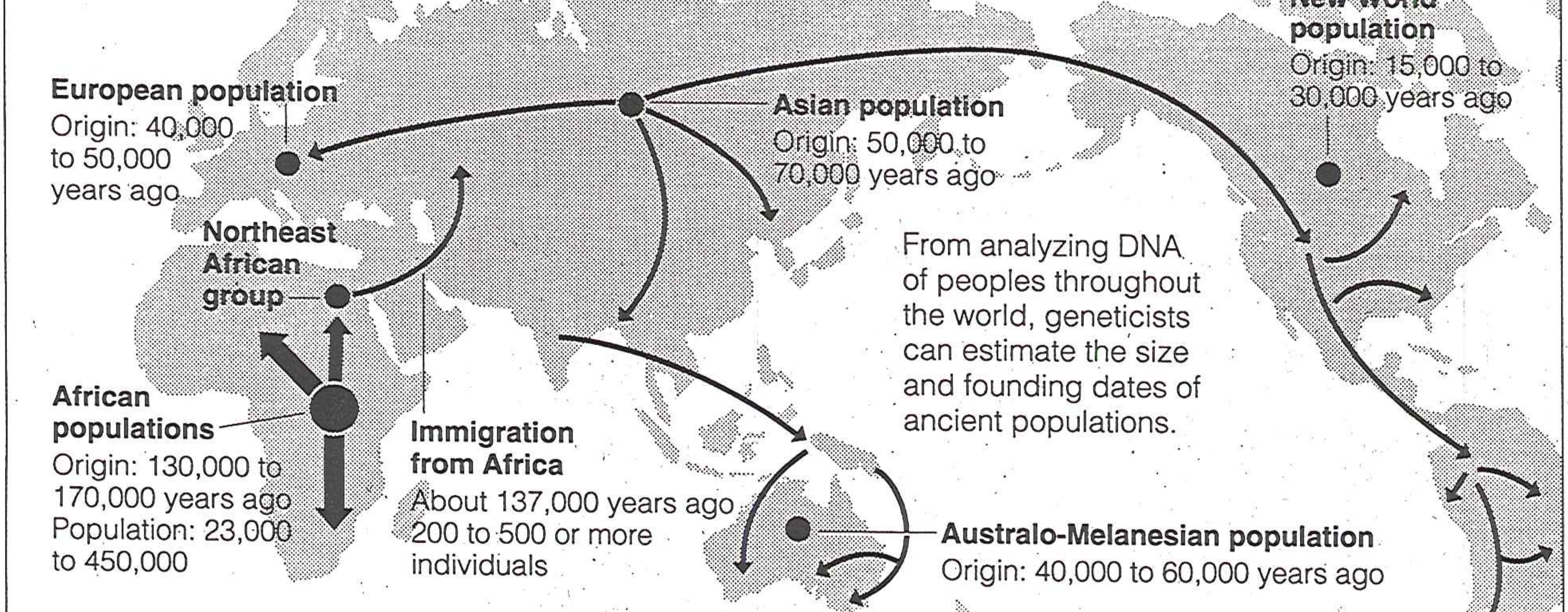
Until a skull and other bones are found, however, the scientists said they would not be able to determine the relationship of their find to any of the known Homo species, all of which are dated at 1.9 million years ago and later, or whether it is a previously unknown species representing a transitional step. In that case, it might even be a more direct ancestral line leading to modern humans.

In any case, the well-preserved jaw, the researchers write in the journal article, represents "the oldest association of hominid remains with stone tools and possibly the earliest well-dated occurrence of the genus Homo." This, they concluded, "promises to add new insights on hominid paleobiology and behavior in this poorly understood time period."

The leaders of the team are Dr.

Continued on Page C5, Column 1

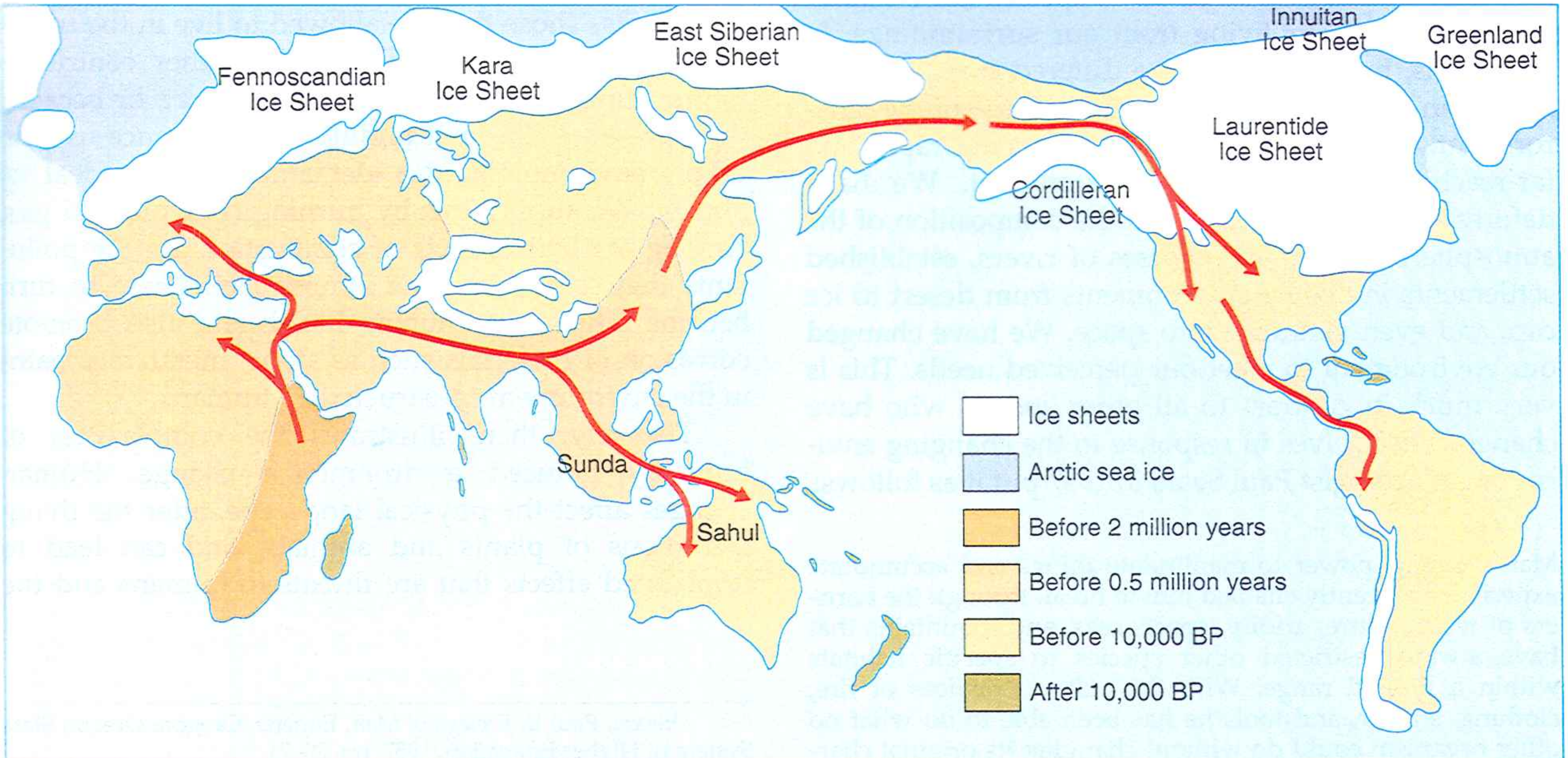
Retracing Footsteps Through DNA



Sources: "The History and Geography of Human Genes" (Princeton University Press); Human evolution conference, Cold Spring Harbor Laboratory

The New York Times

FIGURE T4.2 Humans are latecomers to the Earth. Since their appearance, however, they have spread rapidly, as indicated on this world map. *(Modified from Roberts, Neil,* The Holocene: An Environmental History*, Oxford: Basil Blackwell, 1989, Fig. 3.7, p. 56.)*



Estimates of Past Human Population Sizes (Millions)

year (− means B.C.)	Deevey 1960	McEvedy and Jones 1978	Durand 1977 low	Durand 1977 high	Clark 1977	Biraben 1979	Blaxter 1986[a]	United Nations 1992a	Kremer 1993[b]
−1,000,000	0.125	—	—	—	—	—	—	—	0.125
−300,000	1	—	—	—	—	—	—	—	1
−25,000	3.34	—	—	—	—	—	—	—	3.34
−10,000	—	4.00	—	—	—	—	—	—	4.00
−8000	5.32	—	—	—	—	—	—	—	—
−5000	—	5.0	—	—	—	—	40	—	5.0
−4000	86.5	7	—	—	—	—	—	—	7
−3000	—	14	—	—	—	—	—	—	14
−2000	—	27	—	—	—	—	70[c]	—	27
−1000	—	50	—	—	—	—	100[d]	—	50
−500	—	100	—	—	—	—	—	—	100
−400	—	—	—	—	—	153	162	—	—
−200	—	150	—	—	—	225	231	—	150
1	133	170	270	330	256[e]	252	255	—	170
200	—	190	—	—	—	257	256	—	190
400	—	190	—	—	254[f]	206	206	—	190
500	—	190	—	—	—	207	—	—	—
600	—	200	—	—	237	208	206	—	200
700	—	210	—	—	—	206	207	—	—
800	—	220	—	—	261	224	224	—	220
900	—	240	—	—	—	222	226	—	—
1000	—	265	275	345	280	253	254	—	265
1100	—	320	—	—	—	299	301	—	320
1200	—	360	—	—	384	400	400	—	360
1250	—	—	—	—	—	417	—	—	—
1300	—	360	—	—	—	431	432	—	360
1340	—	—	—	—	378	442	—	—	—
1400	—	350	—	—	—	375	374	—	350
1500	—	425	440	540	427	461	460	—	425
1600	—	545	—	—	498	578	579	—	545
1650	545	545	—	—	516	—	—	—	545
1700	—	610	—	—	641	680	679	—	610
1750	728	720	735	805	731	771	770	—	720
1800	906	900	—	—	890	954	954	—	900
1850	—	1,200	—	—	1,190	1,241	1,241	—	1,200
1875	—	1,325	—	—	—	—	—	—	1,325
1900	1,610	1,625	1,650	1,710	1,668	1,634	1,633	—	1,625
1920	—	—	—	—	—	—	—	—	1,813
1925	—	2,000	—	—	—	—	—	—	—
1930	—	—	—	—	—	—	—	—	1,987
1940	—	—	—	—	—	—	—	—	2,213
1950	2,400	2,500	—	—	—	2,530	2,513	2,516	2,516

year (− means B.C.)	Deevey 1960	McEvedy and Jones 1978	Durand 1977 low	Durand 1977 high	Clark 1977	Biraben 1979	Blaxter 1986[a]	United Nations 1992a	Kremer 1993[b]
1955	—	—	—	—	—	—	—	2,752	—
1960	—	—	—	—	—	—	—	3,020	3,019
1965	—	—	—	—	—	—	—	3,336	—
1970	—	—	—	—	—	3,637	—	3,698	3,693
1975	—	3,900	3,950	4,050	—	—	—	4,079	—
1980	—	—	—	—	—	—	4,415	4,448	4,450
1985	—	—	—	—	—	—	—	4,851	—
1990	—	—	—	—	—	—	—	5,292	5,333

[a] Blaxter's estimate "derives from" those of Biraben (1979) and the United Nations (Blaxter 1986, p. 12), but minor differences from Biraben's figures are not explained.
[b] Kremer's estimate is based on Deevey (1960) up to −25,000, on McEvedy and Jones (1978) from −10,000 to 1900 and on various sources after 1900.
[c] Blaxter's (1986, p. 13) estimate for 1600 B.C. is shown on the line for 2000 B.C.
[d] Blaxter's (1986, p. 13) estimate for 800 B.C. is shown on the line for 1000 B.C.
[e] Clark's (1977, p. 64) estimate for A.D. 14 is shown on the line for A.D. 1.
[f] Clark's (1977, p. 64) estimate for A.D. 350 is shown on the line for A.D. 400.

SOURCES: Deevey (1960); McEvedy and Jones (1978); Durand (1977); Clark (1977); Biraben (1979); Blaxter (1986); United Nations (1992a); Kremer (1993)

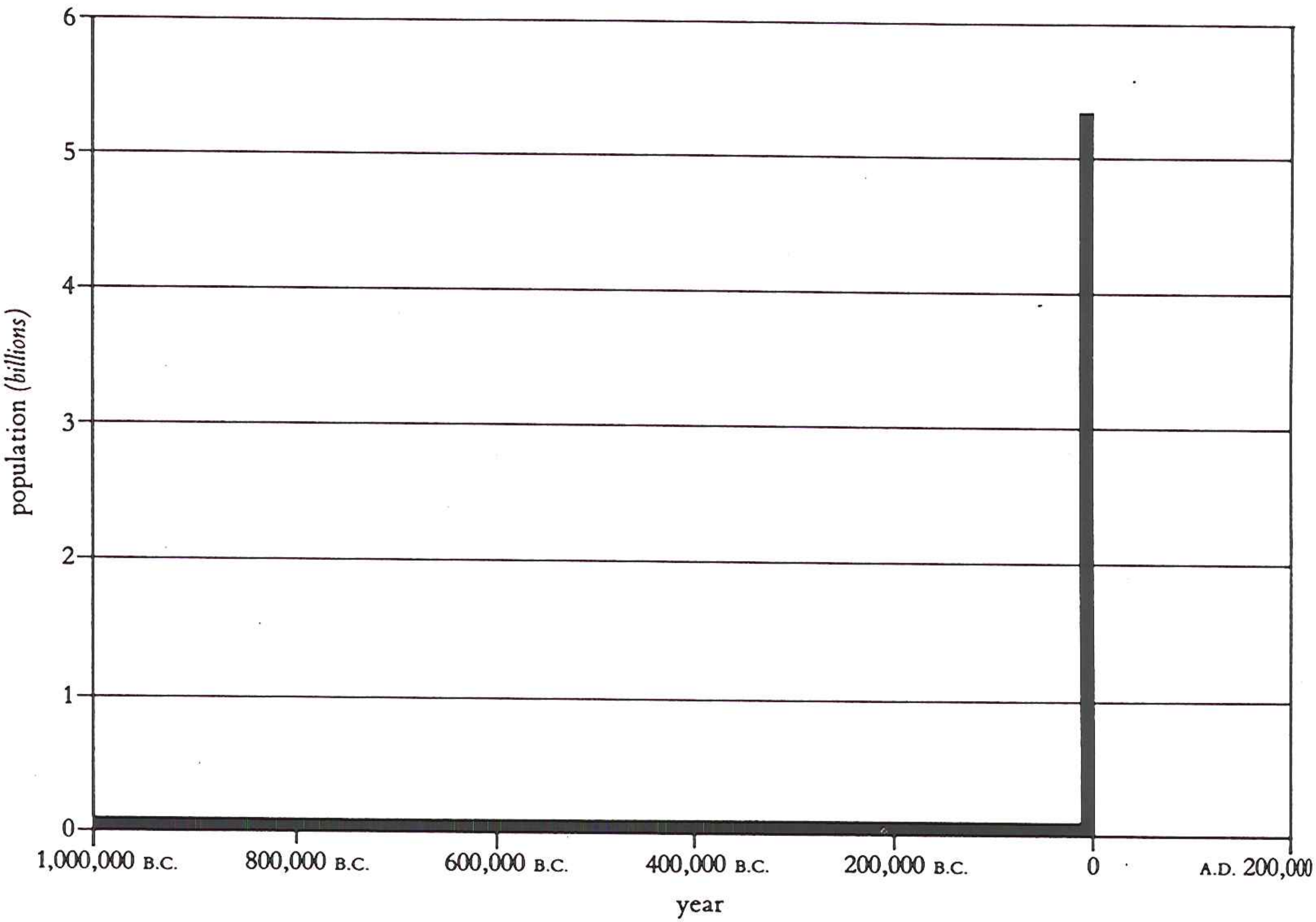


FIGURE 5.1 Estimated human population from a million years ago to the present.
SOURCE OF DATA: Appendix 2

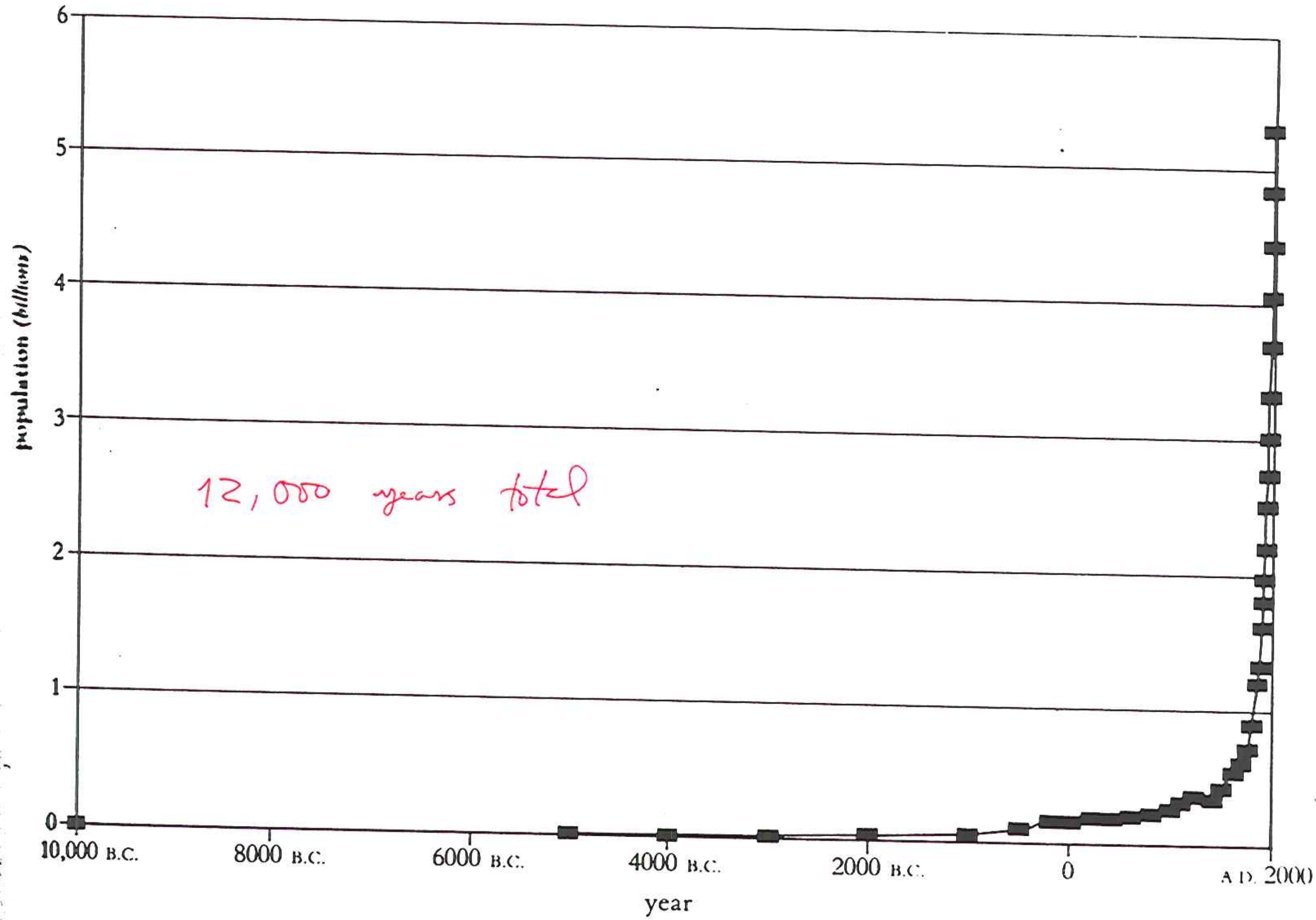


FIGURE 5.2 Estimated human population from the last ice age to the present.
SOURCE OF DATA: Appendix 2

almost all growth
in past 200 years

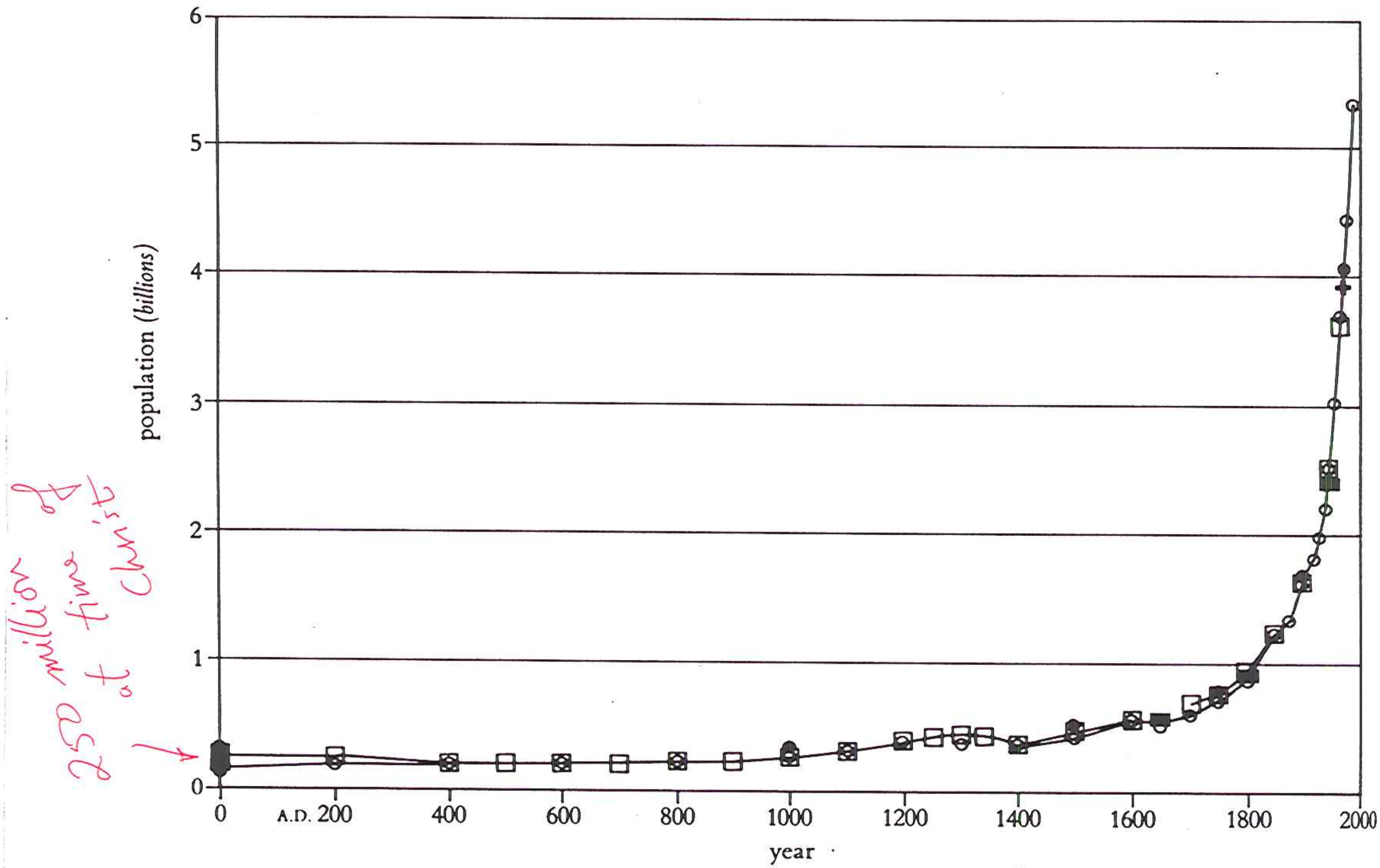
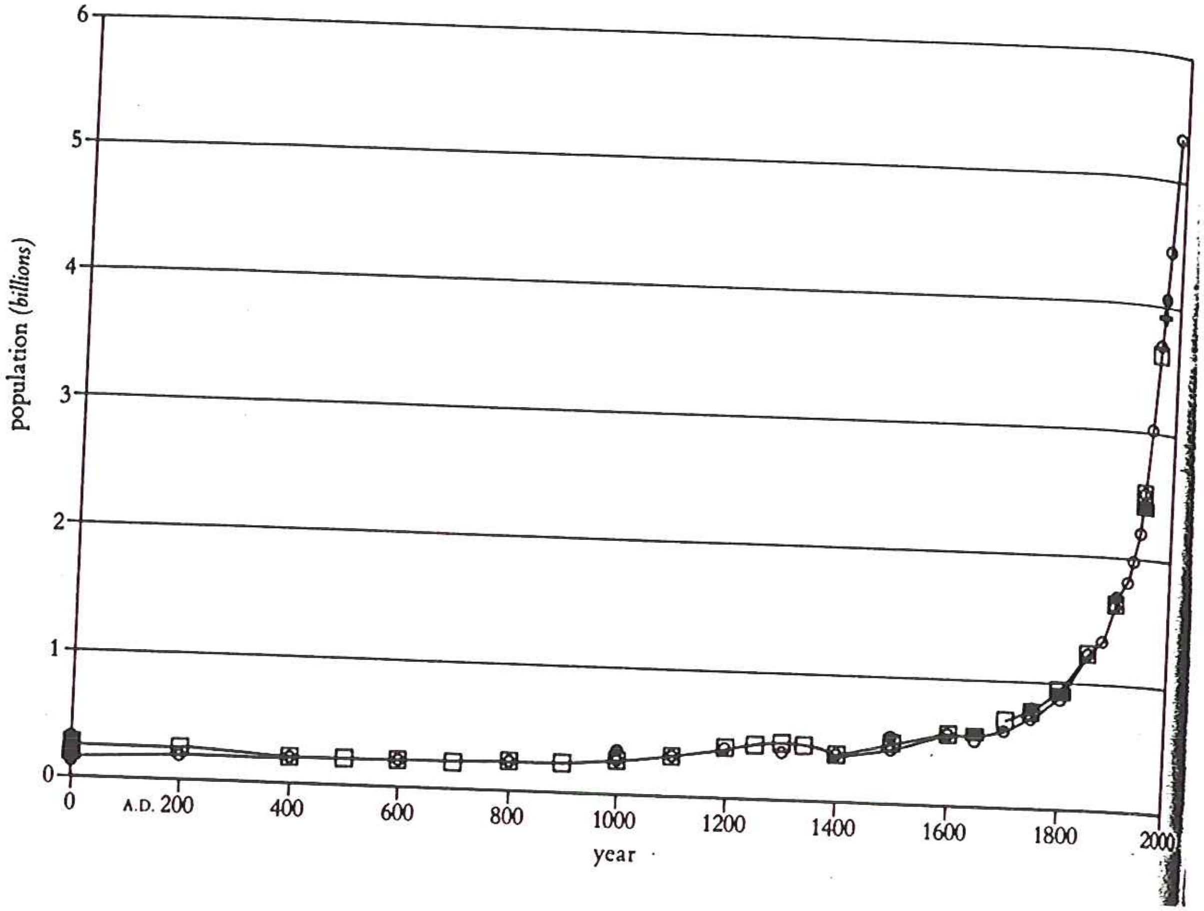
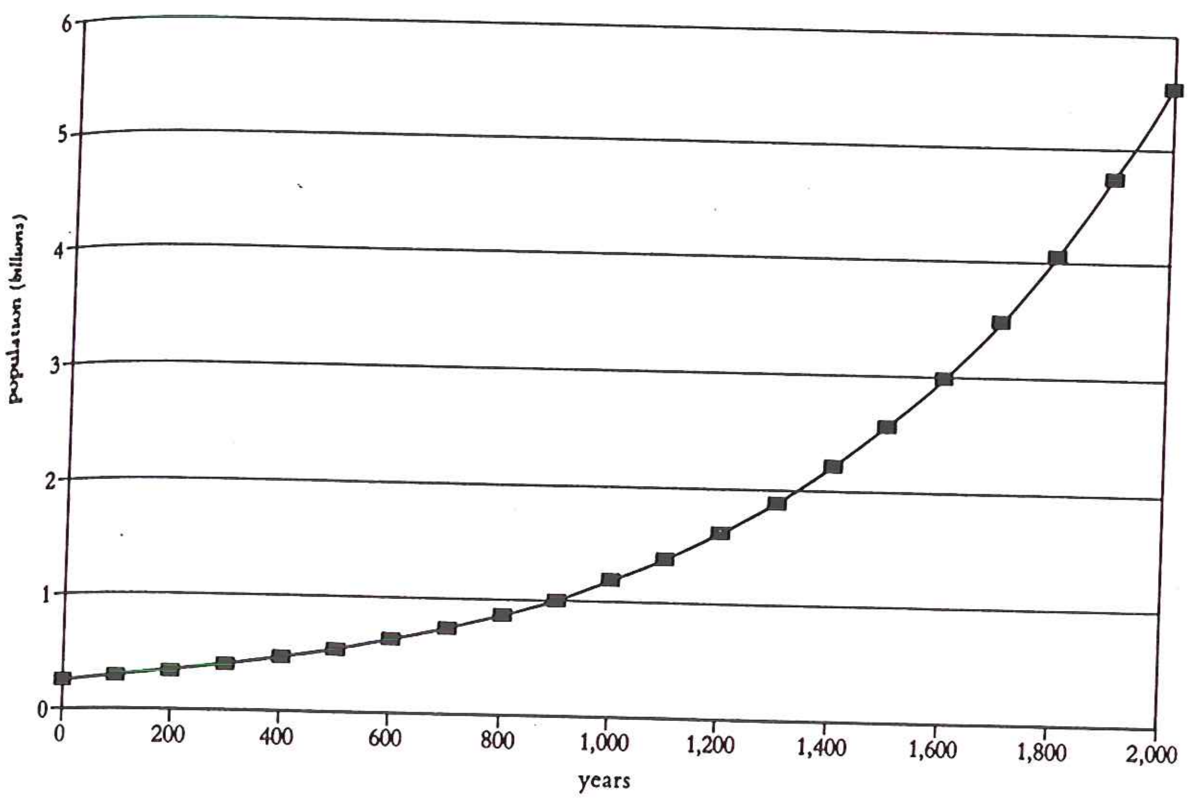


FIGURE 5.3 Estimated human population from A.D. 1 to the present. Different symbols represent estimates from different sources. SOURCE OF DATA: Appendix 2


6
5
4
3
2
1
0
population (billions)
0
A.D. 200
400
600
800
1000
1200
1400
1600
1800
2000
year


6
5
4
3
2
1
0
population (billions)
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
years

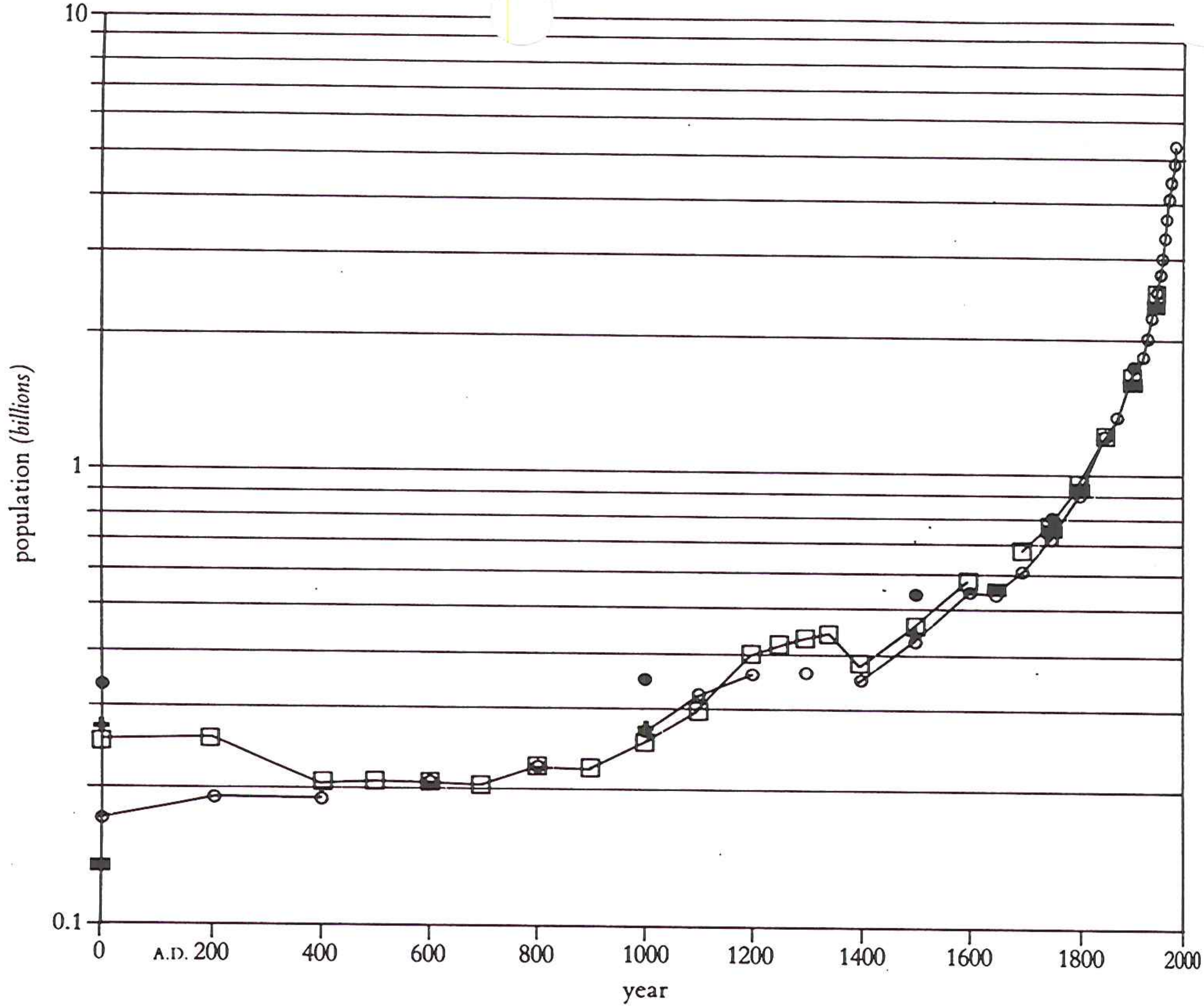


FIGURE 5.12 World population history for the last two millennia, with population plotted on a logarithmic scale. Different symbols represent estimates from different sources. SOURCE OF DATA: Appendix 2

name of evolution	date in the middle	population (*billions*)	doubling time (*years*) before	after
local agricultural	8000 B.C.	0.005	40,000–300,000	1,400–3,000
global agricultural	A.D. 1750	0.75	750–1,800	100–130
public health	1950	2.5	87	36
fertility	1970	3.7	34 (peak)	more than 40 (since 1990)

introduction of new world crops

TABLE 3.1 Calories of Old World and New World crops compared

American crops	million kilocalories per hectare	Old World crops	million kilocalories per hectare
maize	7.3	rice	7.3
potato	7.5	wheat	4.2
manioc	9.9	barley	5.1
		oat	5.5

SOURCE: Crosby (1972, p. 175), using Food and Agricultural Organization statistics for average soil and weather conditions.

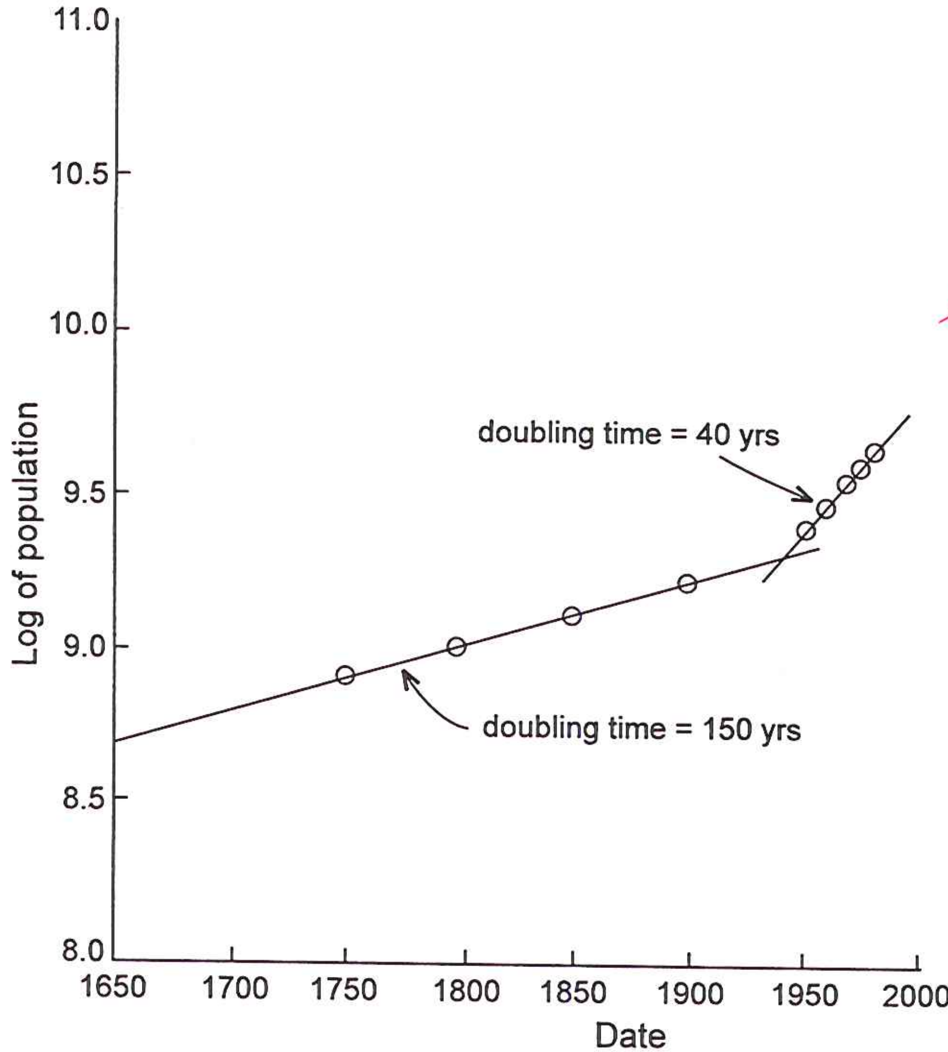


Figure 5.8. Logarithm of the estimated and projected world population, 1650–2100.

homework problem asks you to plot high resolution view of data from 1950–70 and 1970–90 to see effect of fourth "fertility" evolution

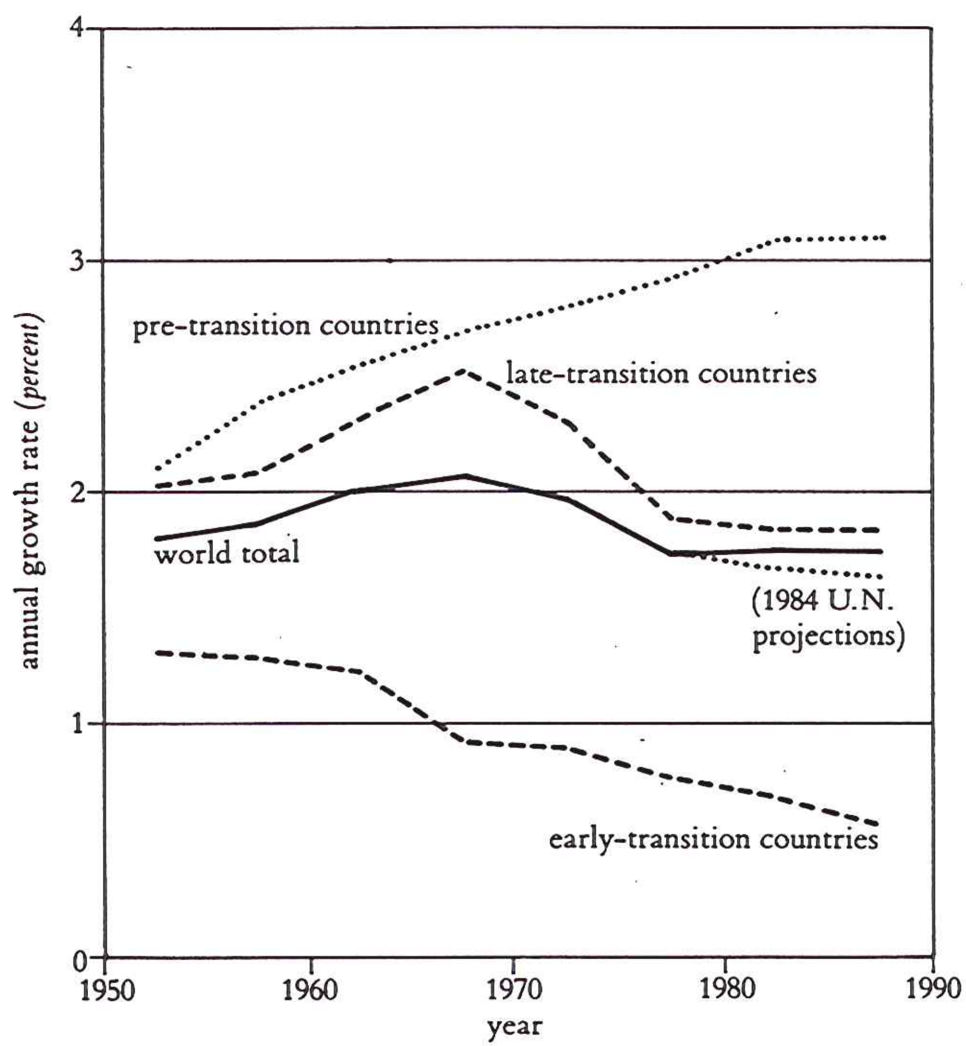
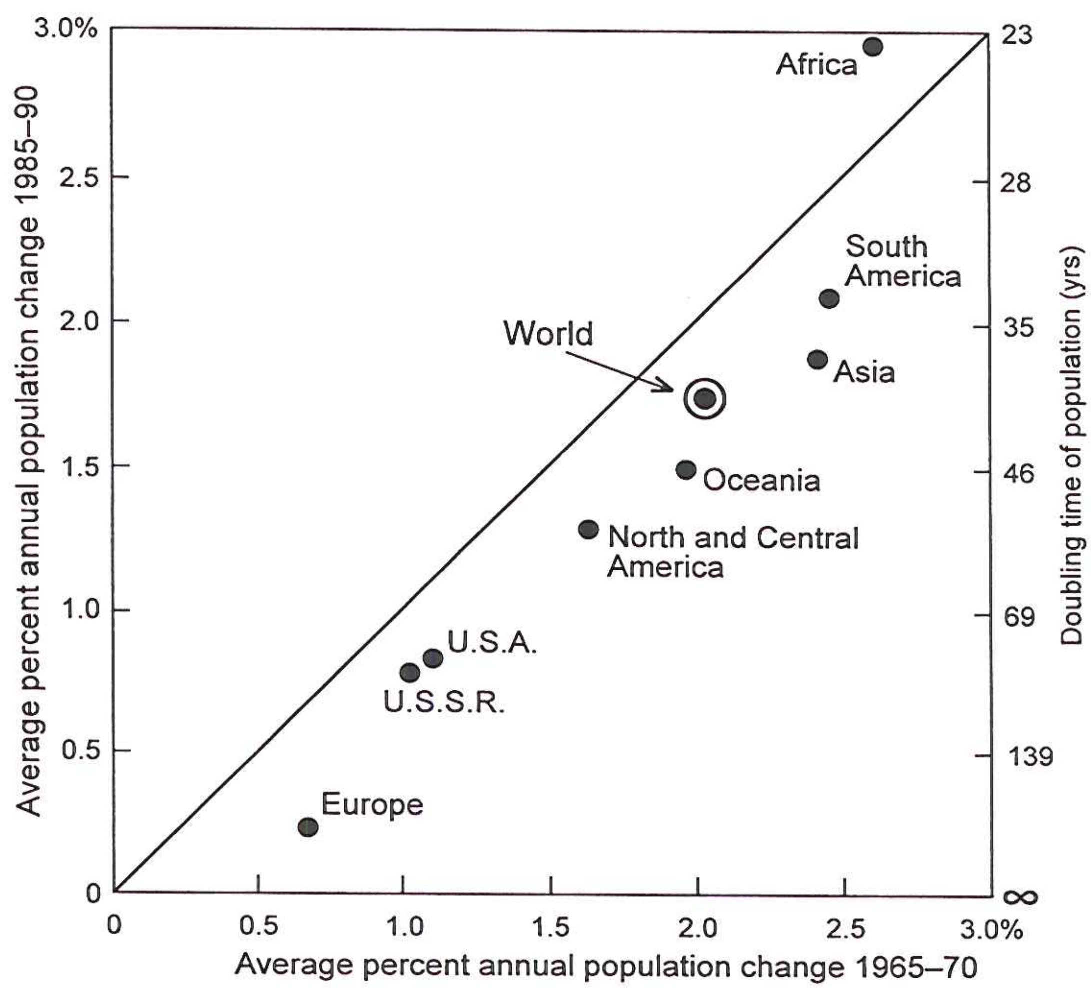


FIGURE 4.2 Global trends in the annual rate of population growth, 1950 to 1990, according to United Nations estimates. For the world total in 1990, the solid line shows the 1990 estimate and the dotted line just below it shows the growth rate projected in 1984; the anticipated decline in the population growth rate did not occur. SOURCE: Horiuchi (1992, p. 761, Fig. 1)

Figure 5.12. Comparison of annual population changes between 1985 and 1990 with those between 1965 and 1970 in several parts of the world.



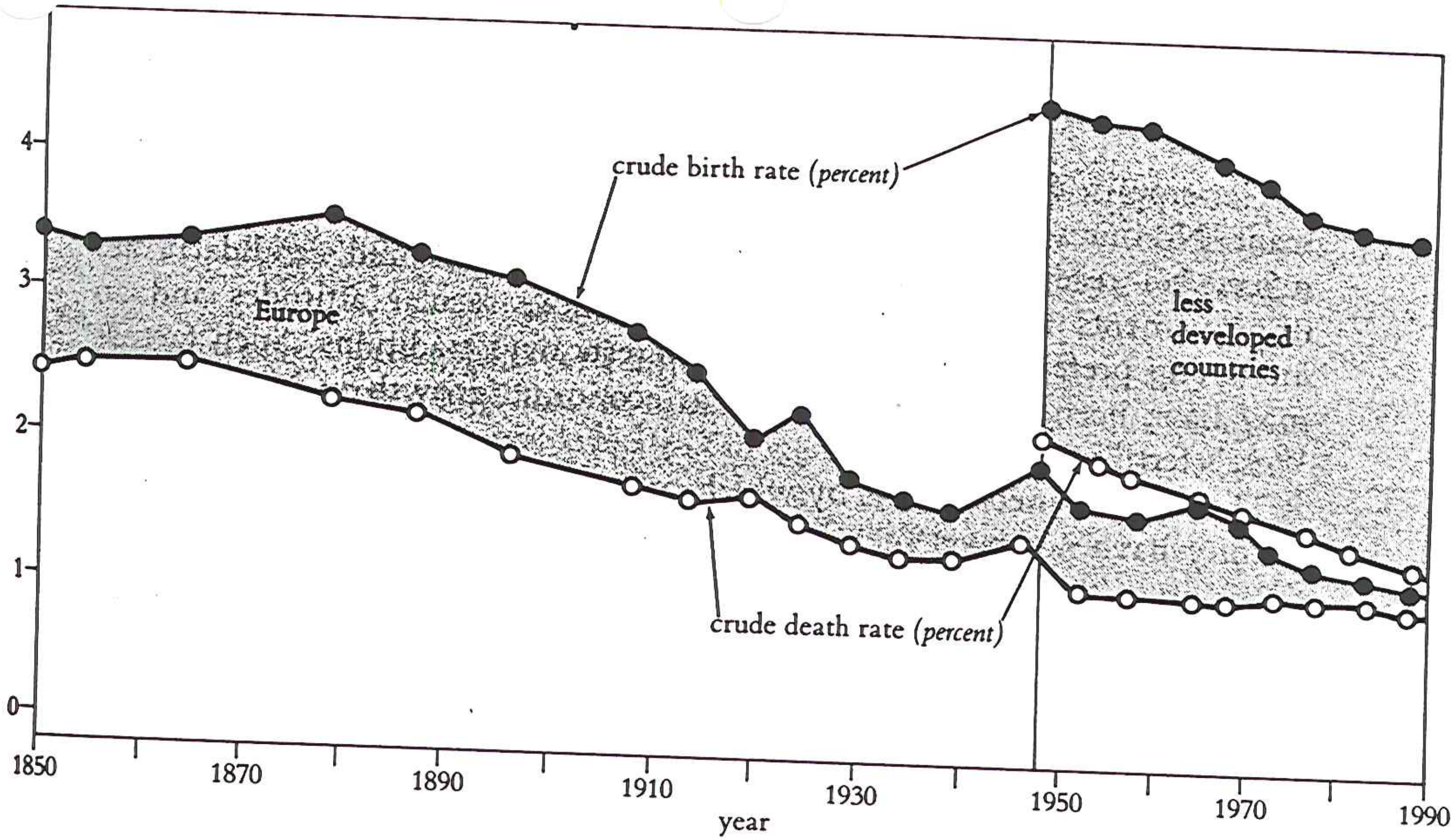
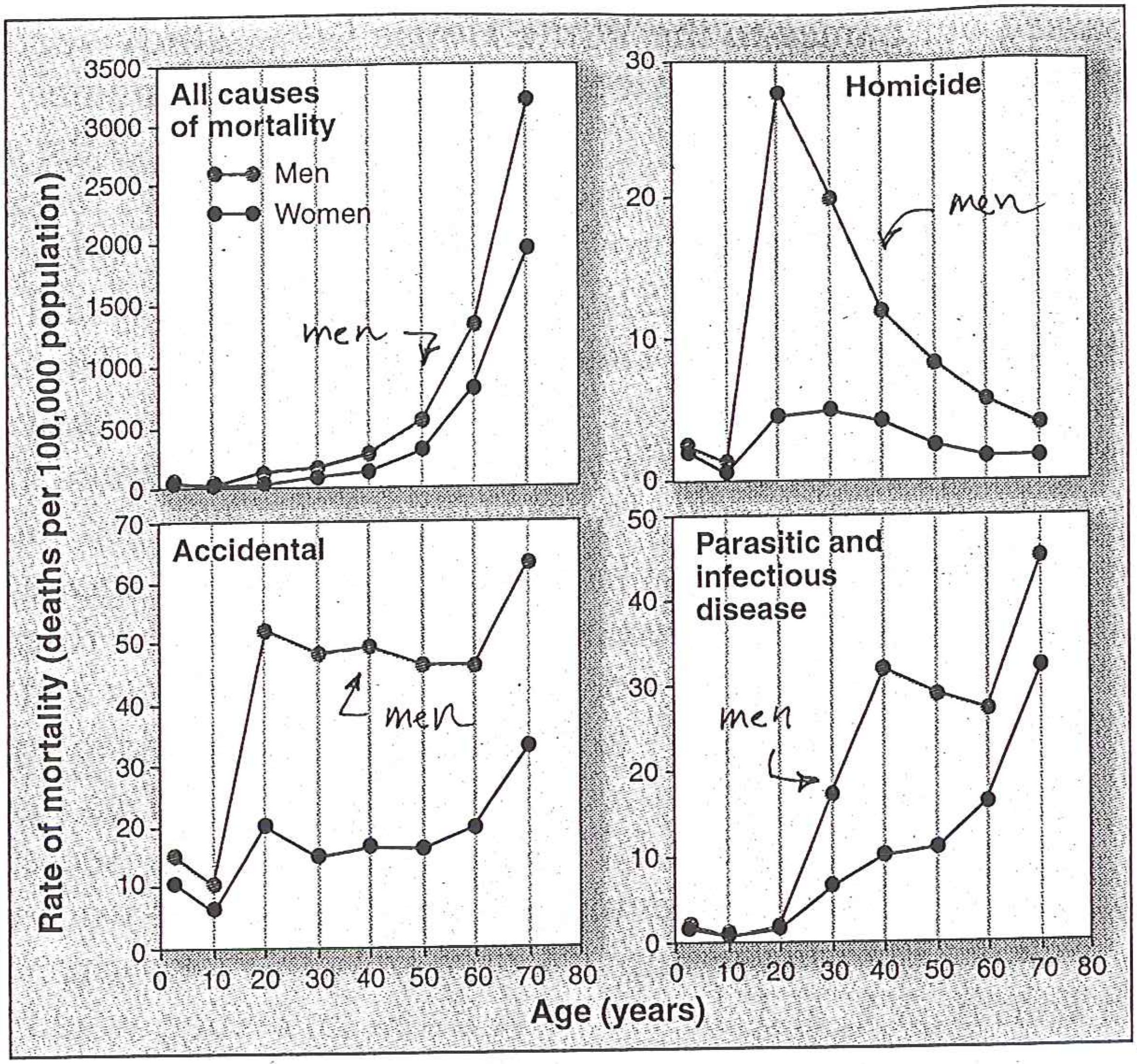


FIGURE 4.4 Crude birth rates and crude death rates in 13 western European countries and 106 less developed countries. The unweighted average understates the global impact of declines in large countries such as China and India. SOURCE: Kelley (1988, p. 1688, Fig. 1)



Sex differences in human mortality. The overall mortality rate in males is higher than that in females from puberty onward (**top left**). The other three graphs show sex differences in mortality rate due to homicide, accidental death, and parasitic and infectious diseases. For all three causes, mortality rate is higher in men than in women, but the timing of the onset of male-biased mortality varies across causes. For death through homicide and accidental causes (**top right, bottom left**), the increase in male-biased mortality begins immediately after puberty. For death caused by parasitic and infectious diseases (**bottom right**), the sex difference in mortality rate becomes apparent much later. [Data for 1997 USA population from (*1*) (www.who.int/whois)] per 1000 births presumably

Figure 13.5.
Child deaths and child births. Each line on the chart represents, for one developing country, the change in under-five mortality rate (USMR) and total fertility rate (TFR) over the period from 1960 to 1989. The intermediate point on each line represents data for the year 1980. On the right-hand side of the graph is shown the present under-five mortality rate of some of the most populous developing countries today. (Grant 1992); see also Brass and Jolly 1993, and Eubank and Gribble 1993)

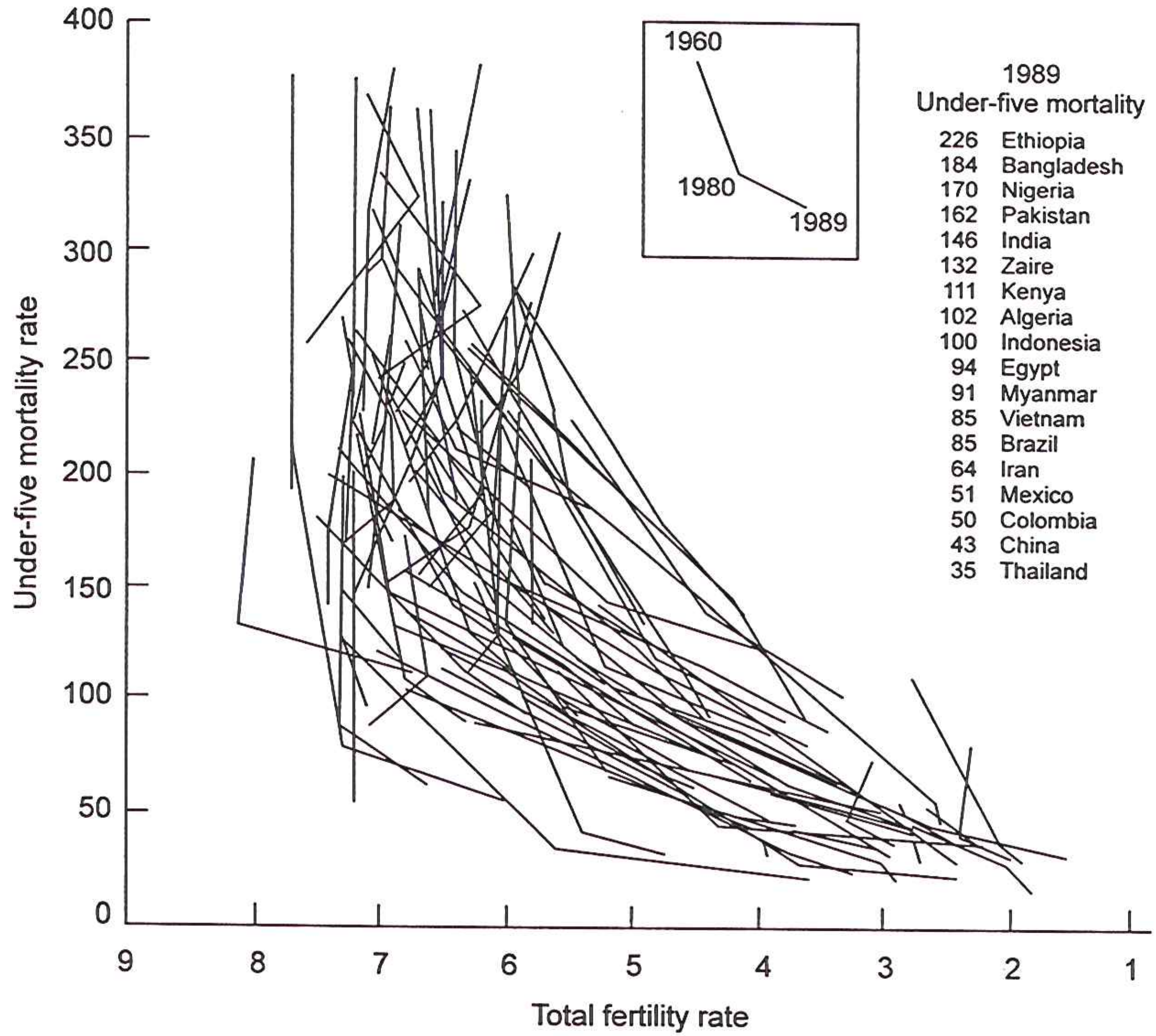
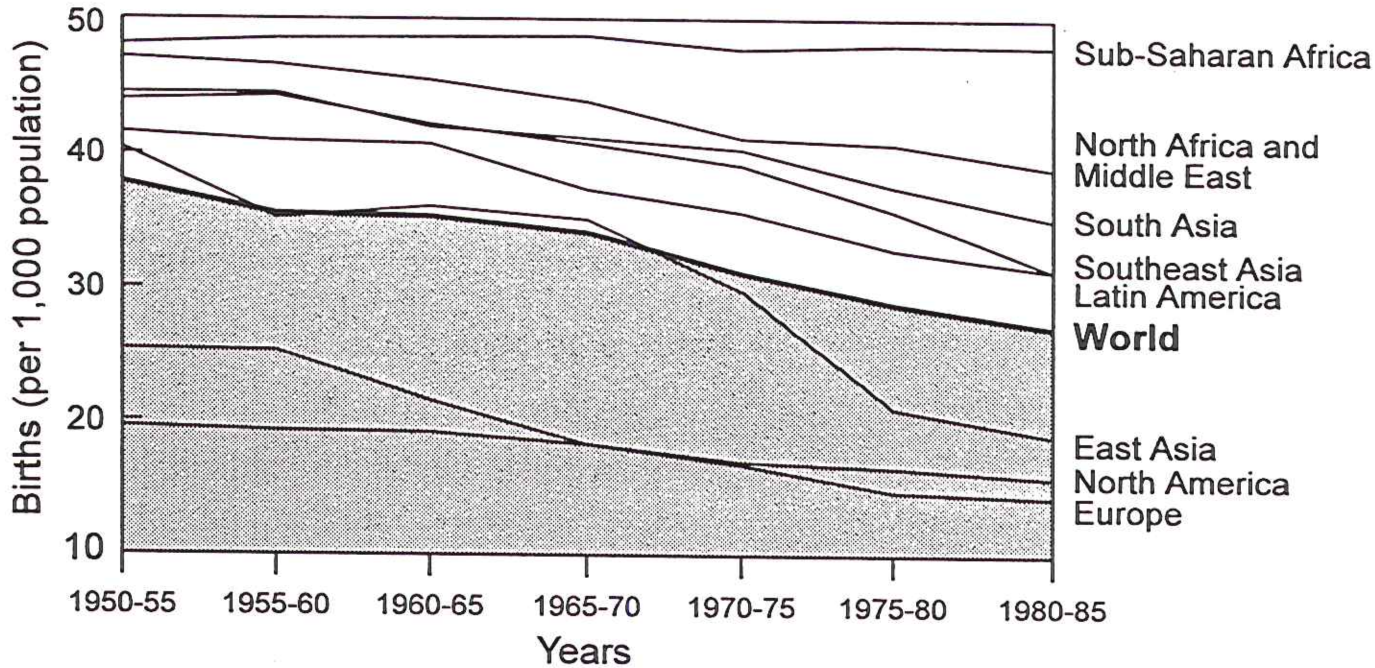


Figure 5.10. Birthrates in regions throughout the world have declined since the end of World War II. The only exceptions to this trend are birthrates in sub-Saharan Africa. Africa could account for nearly a quarter of the world's population by the late twenty-first century. (Caldwell and Caldwell 1990)



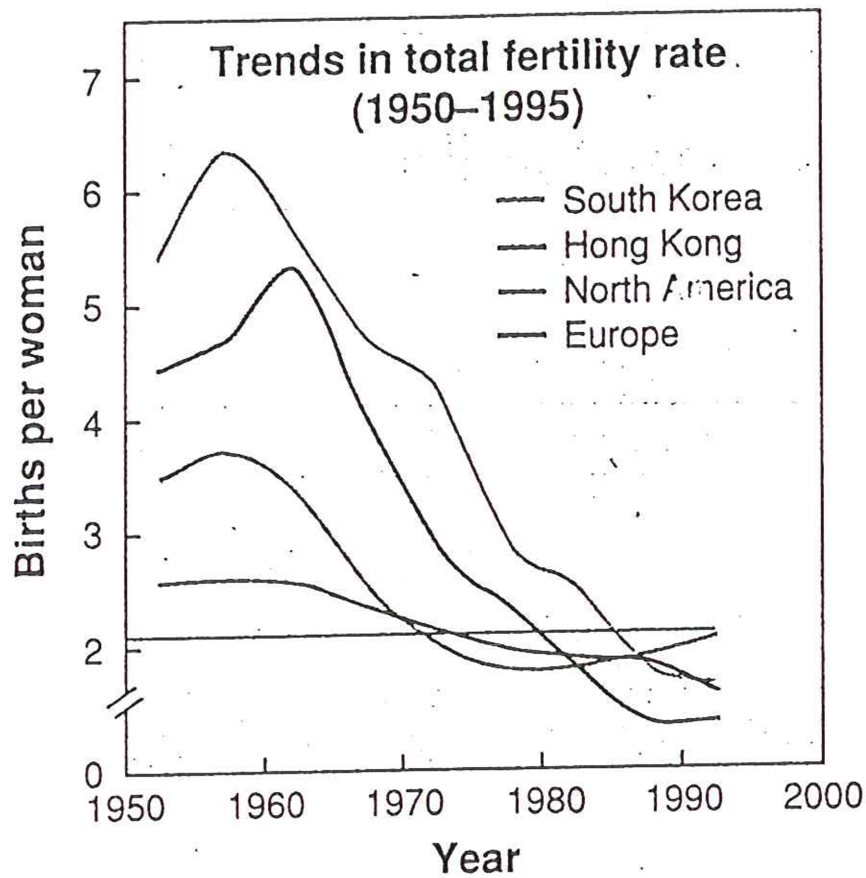

Trends in total fertility rate
(1950–1995)
South Korea
Hong Kong
North America
Europe
Births per woman
0
2
3
4
5
6
7
1950
1960
1970
1980
1990
2000
Year

TABLE 8.1 Total fertility rates in 1990, by region

region	1990 total fertility rate	region	1990 total fertility rate
world	3.3		
U.N. group I		U.N. group II	
Europe	1.8	Africa	6.5
Northern America	1.8	China	2.5
Oceania	3.2	India	4.4
USSR	2.4	Latin America	4.1
		Other Asia	5.0

SOURCE: United Nations (1992a, p. 10)

One-Child Rule: China Rethinks Iron Hand

Continued From Page 1

her one and only child. She said a shift in approach would be welcome.

"I think that if these policies can be implemented it would be better for all of us," she said. "It would be a big improvement for Chinese women."

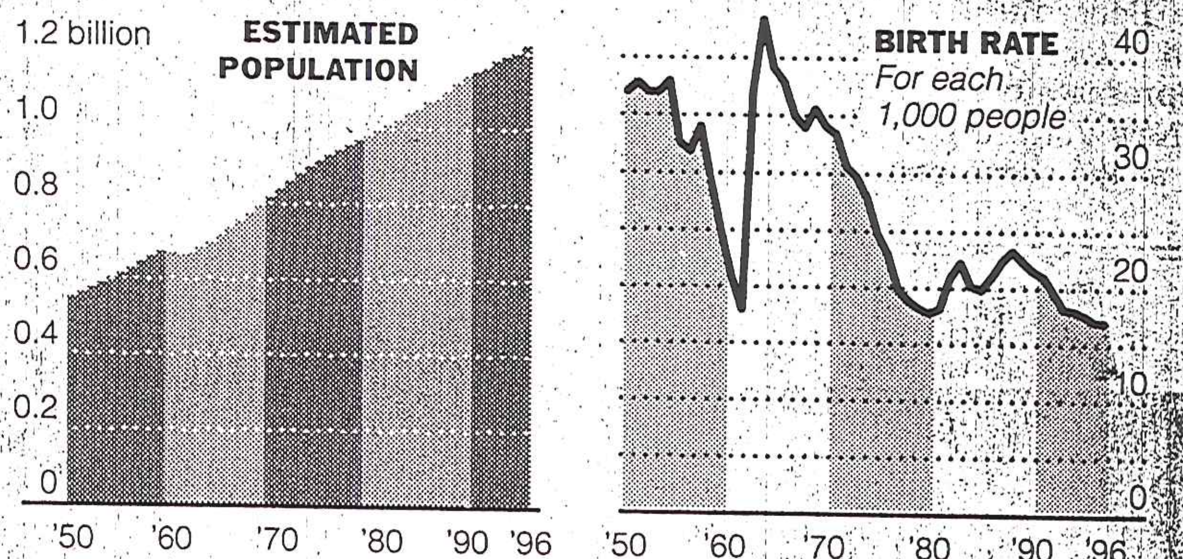
In recent years, the Family Planning Program has increasingly seemed to be an anachronism. High-powered couples who choose jobs and buy homes and travel the world are thrown back into a Mao-era time warp when they want to have a child, which in most places still requires gaining permits from the local government and a woman's employer before pregnancy occurs.

Women can be turned down if their company or neighborhood has exceeded its quota of births for the year. And couples who dare to have a child without permits, or — worse — an illegal second child, can face heavy financial penalties, job loss or, in some cases, police detention.

AT ISSUE

Restraining Population, and Parents

After decades of tight control, China's state family planners are changing their tactics for restricting the number of children in each family. The population has risen even as birth rates have declined.



Sources: World Bank World Development Indicators, State Statistical Bureau of China

The New York Times

Going Down

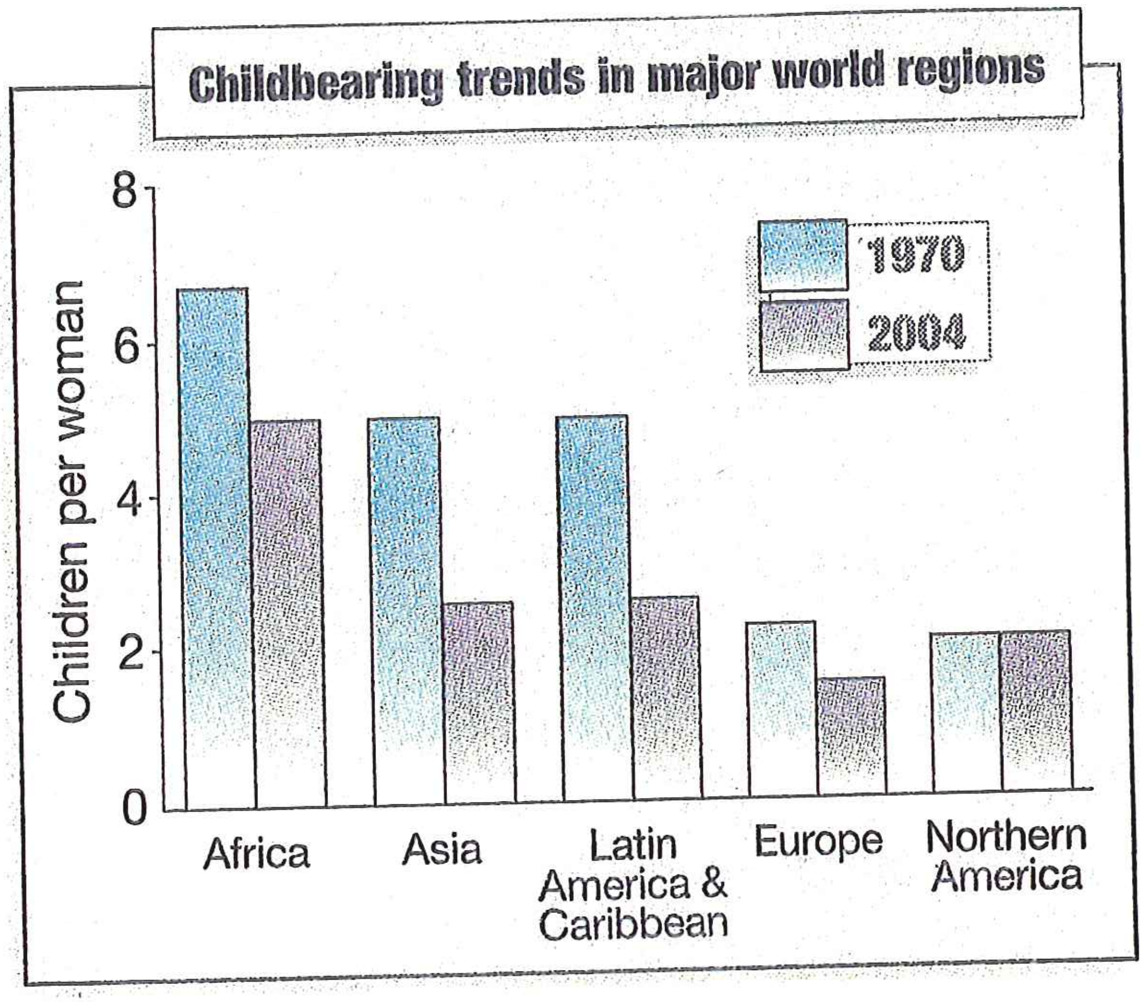
Places in 1995 where the fertility rate — the average number of children born per woman — was equal to or less than the replacement level (2.1 children per woman). Places that have joined the list since 1975 are shown in **bold** type.

1995 fertility rate

Italy	1.24	Russia	1.53	**Czech Republic**	1.68	**Poland**	1.89
Spain	1.27	**Bulgaria**	1.53	Hungary	1.69	**Austria**	1.89
Germany	1.30	**Estonia**	1.58	**France**	1.70	**China**	1.92
Hong Kong	1.32	Netherlands	1.59	**Barbados**	1.73	**Yugoslavia**	1.93
Slovenia	1.36	**Macau**	1.60	Canada	1.74	**Thailand**	1.94
Greece	1.38	**Cuba**	1.60	Denmark	1.75	**Bahamas**	1.95
Austria	1.47	Belgium	1.62	**Lithuania**	1.78	Sweden	2.01
Japan	1.48	Ukraine	1.64	Britain	1.78	**Ireland**	2.01
Bosnia and Herzegovina	1.50	Latvia	1.64	**Singapore**	1.79	**Martinique**	2.05
Romania	1.50	**South Korea**	1.65	Finland	1.83	United States	2.05
Portugal	1.52	Croatia	1.65	**Slovakia**	1.85	Malta	2.08
Switzerland	1.53	Luxembourg	1.66	**Norway**	1.88	**Macedonia**	2.10
		Belarus	1.67			**Georgia**	2.10
						North Korea	2.10

Source: United Nations

The New York Times



Childbearing trends in major world regions
Children per woman
8
6
4
2
0
1970
2004
Africa
Asia
Latin America & Caribbean
Europe
Northern America

Not Malthus

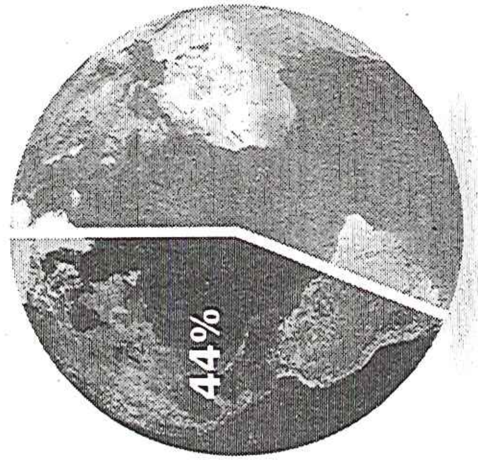
Percentage of world population living in countries with a fertility rate at or below replacement level.

1975

Total world population **4.08 billion**

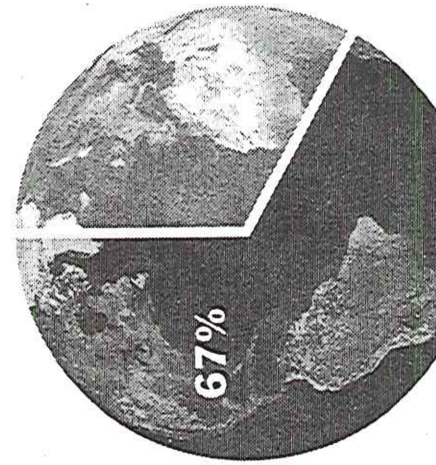
1997

Total world population **5.85 billion**



2015

Total world population **7.29 billion**



Source: United Nations

The New York Times

Going Down

Places in 1995 where the fertility rate — the average number of children born per woman — was equal to or less than the replacement level (2.1 children per woman). Places that have joined the list since 1975 are shown in **bold** type.

1995 fertility rate

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Hong Kong	1.32	Netherlands	1.59	**Barbados**	1.73	**Yugoslavia**	1.93
Slovenia	1.36	**Macau**	1.60	Canada	1.74	**Thailand**	1.94
Greece	1.38	**Cuba**	1.60	Denmark	1.75	**Bahamas**	1.95
Austria	1.47	Belgium	1.62	**Lithuania**	1.76	Sweden	2.01
Japan	1.48	Ukraine	1.64	Britain	1.78	**Ireland**	2.01
Bosnia and Herzegovina	1.50	Latvia	1.64	**Singapore**	1.79	**Martinique**	2.05
Romania	1.50	**South Korea**	1.65	Finland	1.83	United States	2.05
Portugal	1.52	Croatia	1.65	**Slovakia**	1.85	Malta	2.08
Switzerland	1.53	Luxembourg	1.66	**Norway**	1.88	**Macedonia**	2.10
Bosnia and Herzegovina		**Belarus**	1.67			**Georgia**	2.10
						North Korea	2.10

Source: United Nations

The New York Times

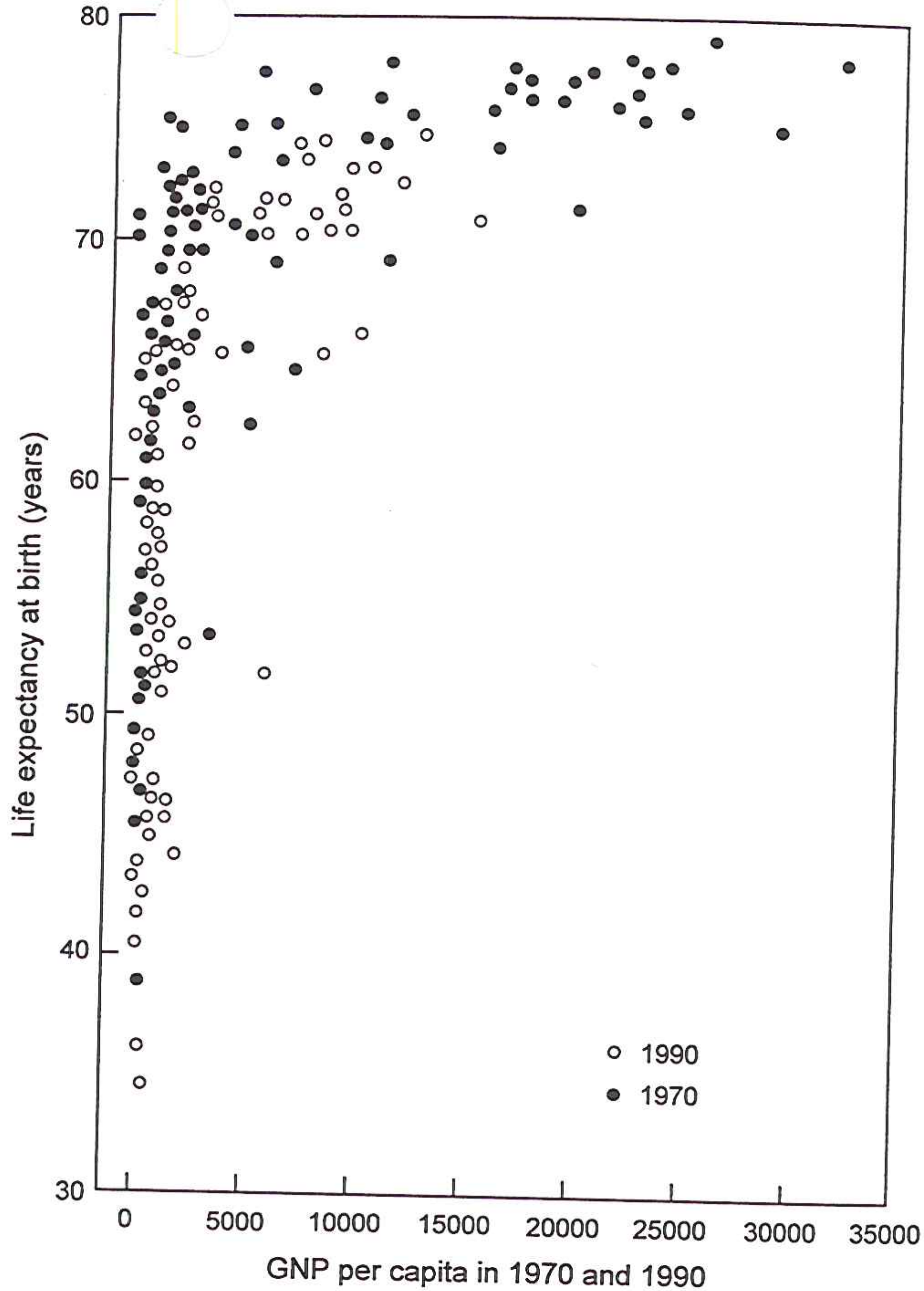


Figure 5.26.
Life expectancy at birth in relation to income in countries for which data were available in 1970 and in 1990. Income is computed as gross national product per capita (GNPPC) and is plotted in 1990 U.S. dollars. (Wilkinson 1994)

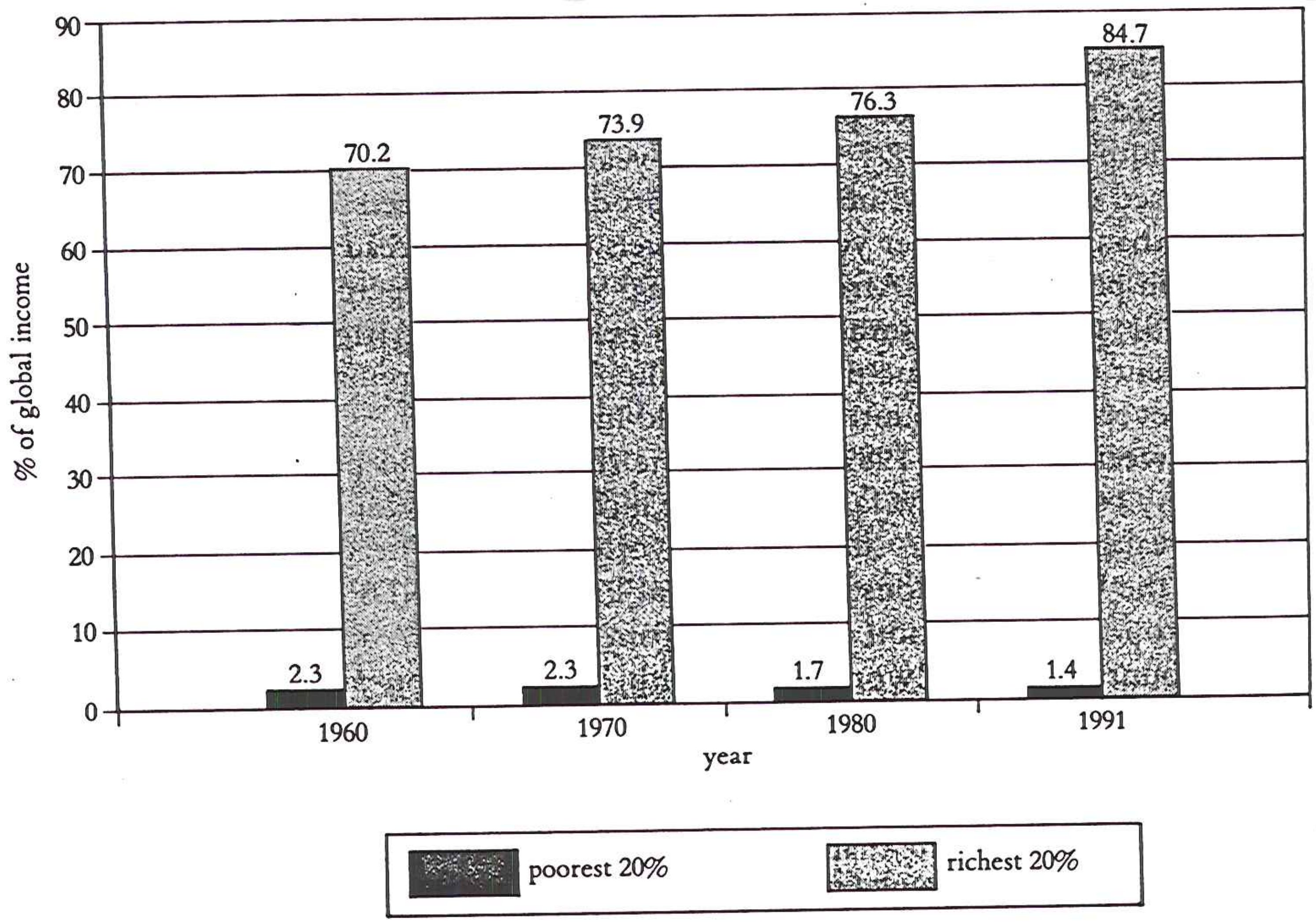


FIGURE 4.1 Fraction of global income received by the poorest 20 percent of people and the richest 20 percent of people from 1960 to 1991, according to the average gross national product per person of different countries. SOURCE: based on United Nations Development Program (1992, pp. 34, 36)

TABLE 1.3 Estimates of Population, Poor and Hungry (millions of people)

Region	**Hunger (1995)***	**Region**	**Poverty (1993)**
Africa	241	Sub-Saharan Africa	218.6
China	210	China	372.3
Eastern Europe and Central Asia	6.3	Eastern Europe and Central Asia	14.5
Latin America and the Caribbean	65	Latin America and the Caribbean	109.6
Middle East	29	Middle East and North Africa	10.7
South and Southeast Asia	337	South Asia	514.7
North America	7	North America	0†
Pacific OECD	1	Pacific OECD	0†
Western Europe	3	Western Europe	0†
World	889	**World**	1313.9

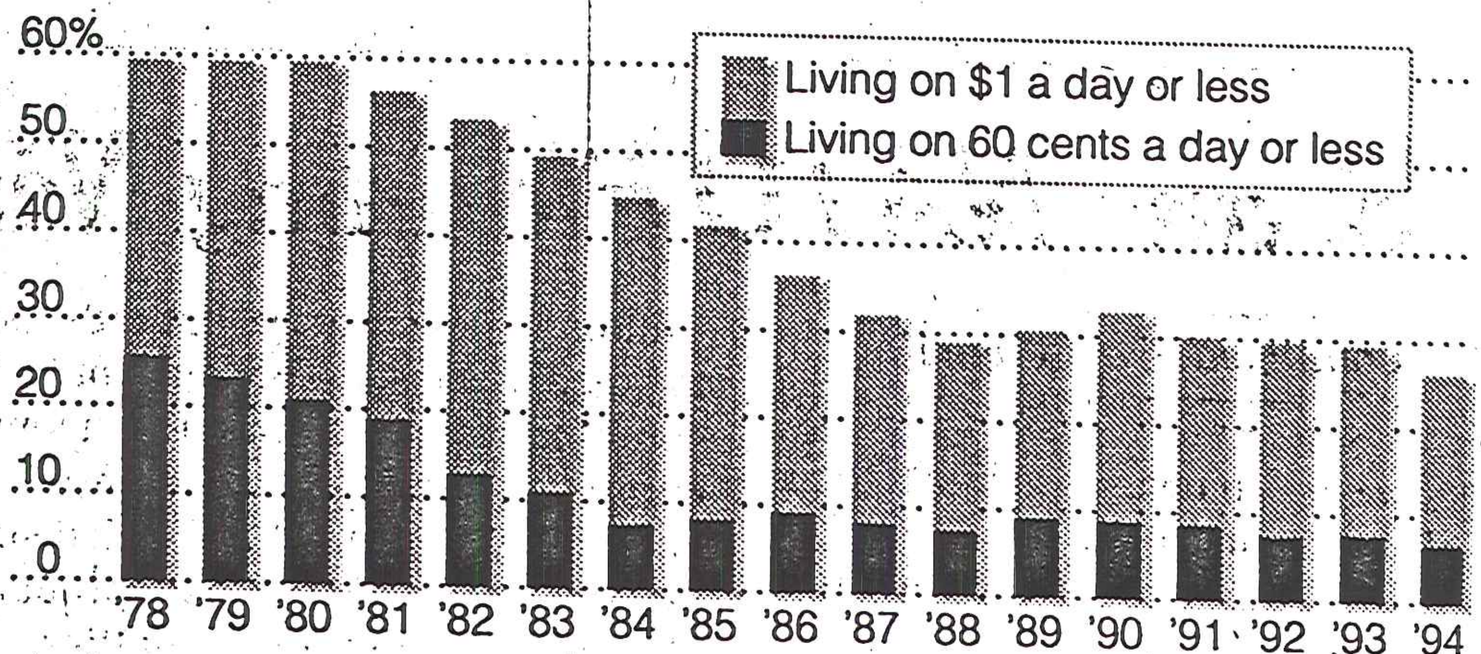
Source: For data on hunger, Raskin et al. (1998); for data on poverty, World Bank (1999).

* Data for hunger are taken from the Reference Scenario in Raskin et al. (1998). See also Chapter 3.
† A different measure of poverty is used for OECD countries.

BY THE NUMBERS

China's Poorest Masses

Although progress has been made in reducing poverty, more than one-quarter of all Chinese – about 350 million people – subsist on less than $1 a day. Of these, at least 60 million are on the edge of starvation, with less than 60 cents a day. Shown are the percentages of Chinese living at these levels, based on a 1996 World Bank report.



Sources; World Bank; Chinese State Statistical Bureau

The New York Times

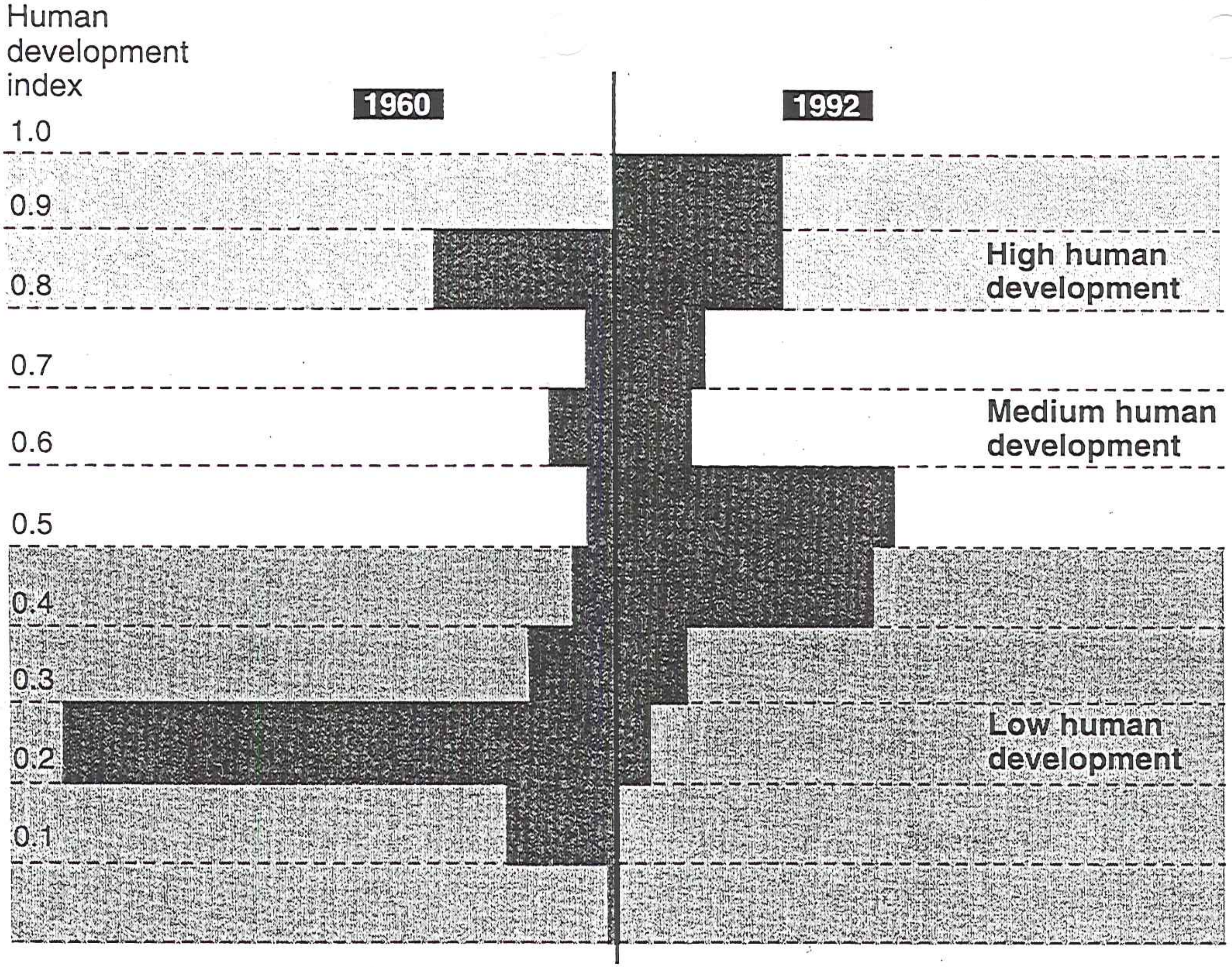


FIGURE 2.2 Distribution of the world's population by decile of the Human Development Index (HDI), 1960 versus 1992. The HDI provides a convenient and graphic indicator of changes in the human condition by combining four indicators of well-being in the population of a nation: life expectancy at birth, adult literacy, school enrollment ratio, and real GDP per capita. Source: UNDP (1995). Courtesy of Oxford University Press.

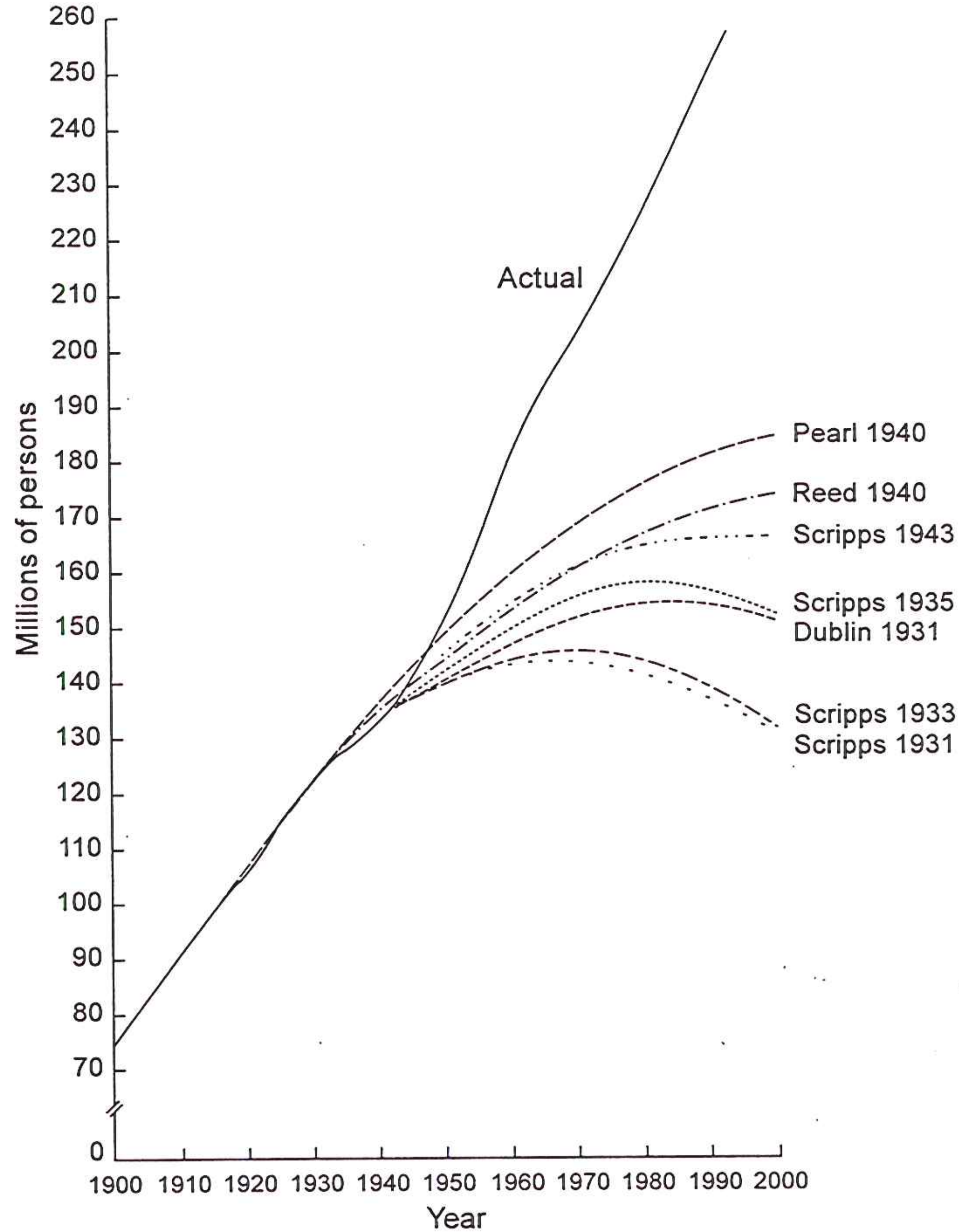
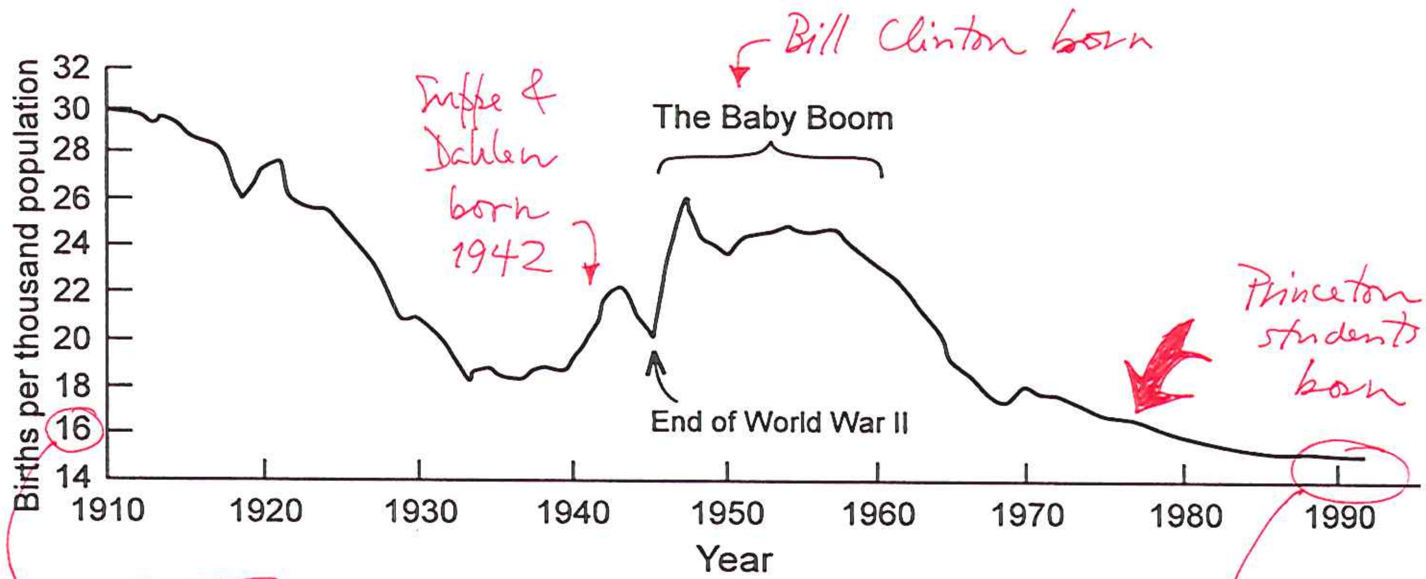


Figure 5.13. U.S. population forecasts made between 1931 and 1943, and the actual population increase during the twentieth century.

Figure 5.14. The birthrate in the United States between 1910 and 1992. (After Population Profile, Population Reference Bureau, March 1967; recent data from U.S. Census Bureau)



$\boxed{b_t = 1.6\%}$

$b_t = 1.4\%$

$\Rightarrow$

$(.014)(2)(67) = 1.8$ babies per woman in US today

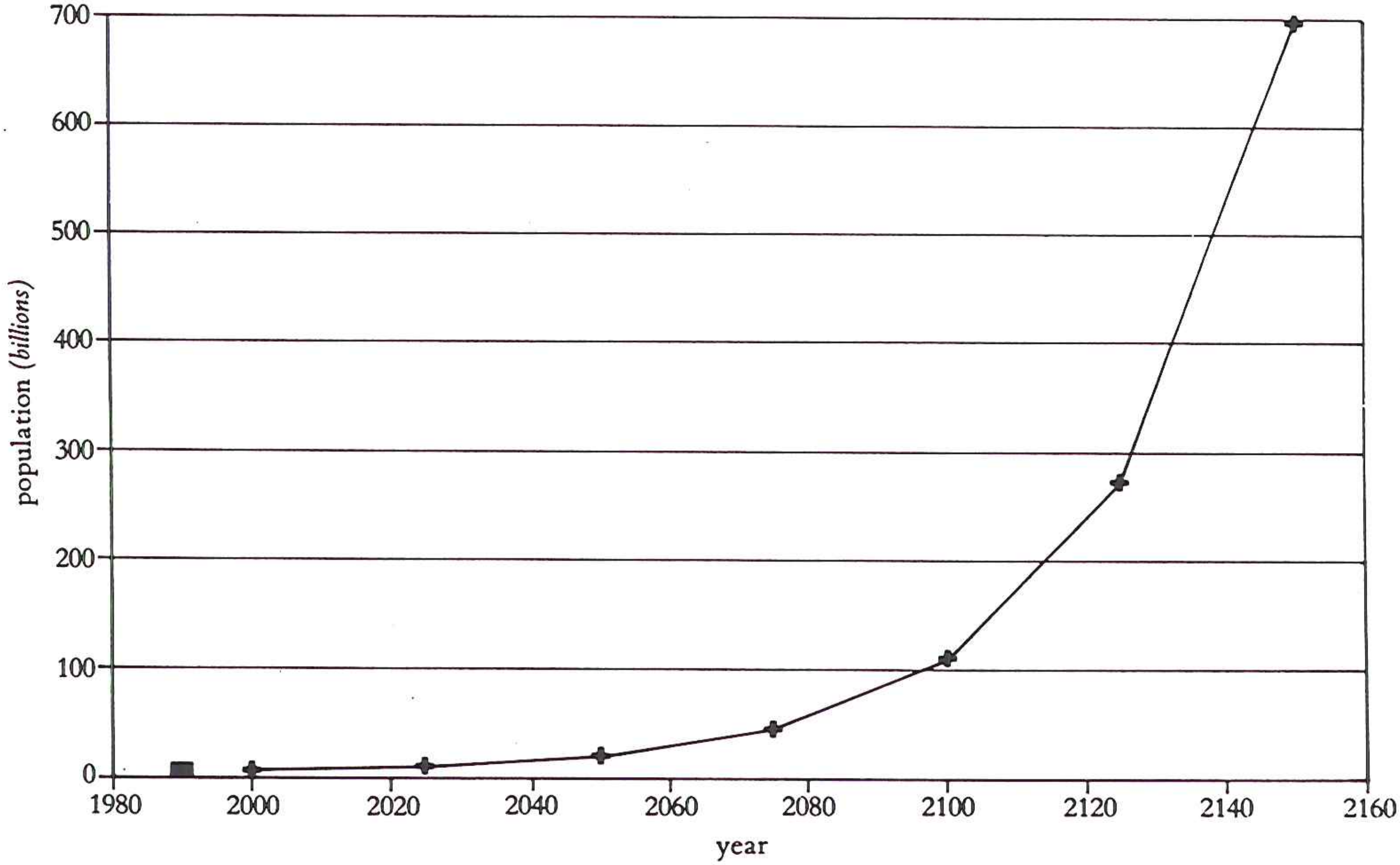


FIGURE 8.1 United Nations' projection of world population, assuming fertility remains constant at its 1990 levels in different regions. SOURCE: original figure drawn according to data of United Nations (1992a)

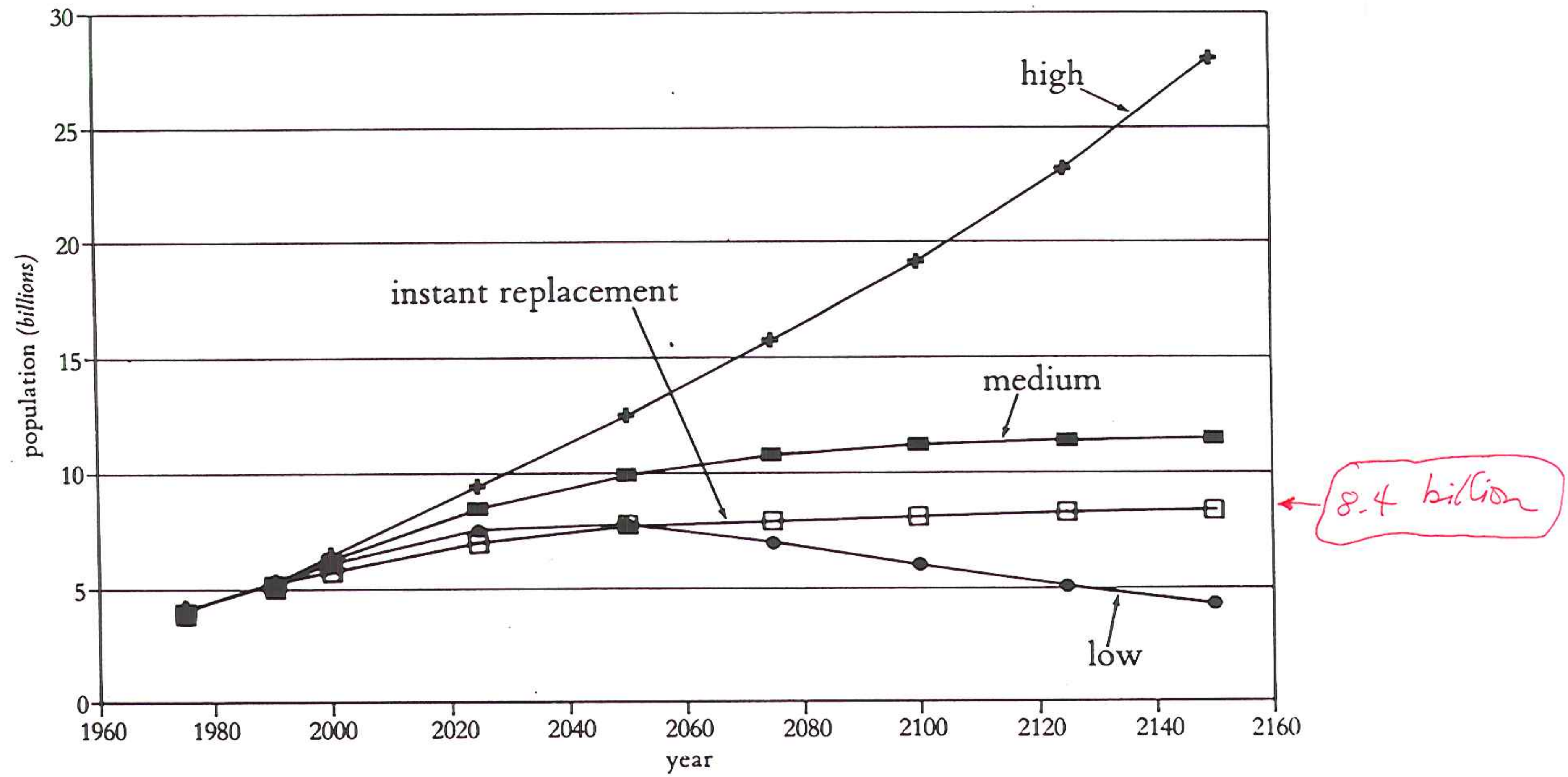
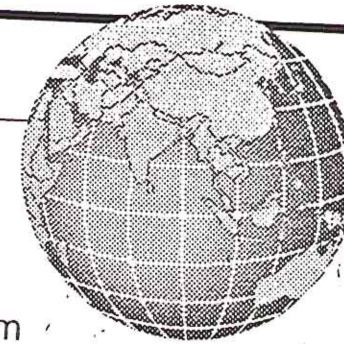


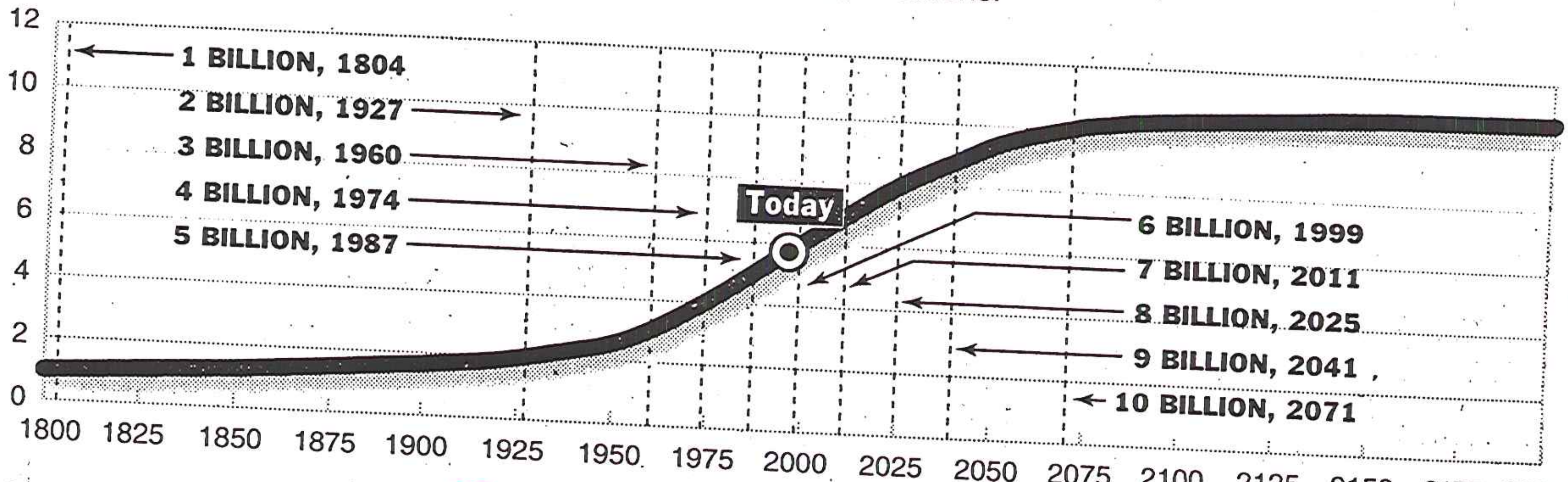
FIGURE 8.2 United Nations' projections of world population, according to high, medium, low and instant-replacement scenarios. SOURCE: original figure drawn according to data of United Nations (1992a)

STATUS REPORT

The Population Explosion Slows Down



A new United Nations study has found that the world's population is growing more slowly than was expected. This suggests that the world's population, now 5.77 billion, will stabilize just after the year 2200 at 10.73 billion. Shown is the world population from 1800 to stabilization based on United Nations projections, in billions.



Source: United Nations

The New York Times

New York Times November 17, 1996 update of medium projection based on latest fertility data (r_t = 1.5% rather than 1.6%)

11 billion rather than 12 billion

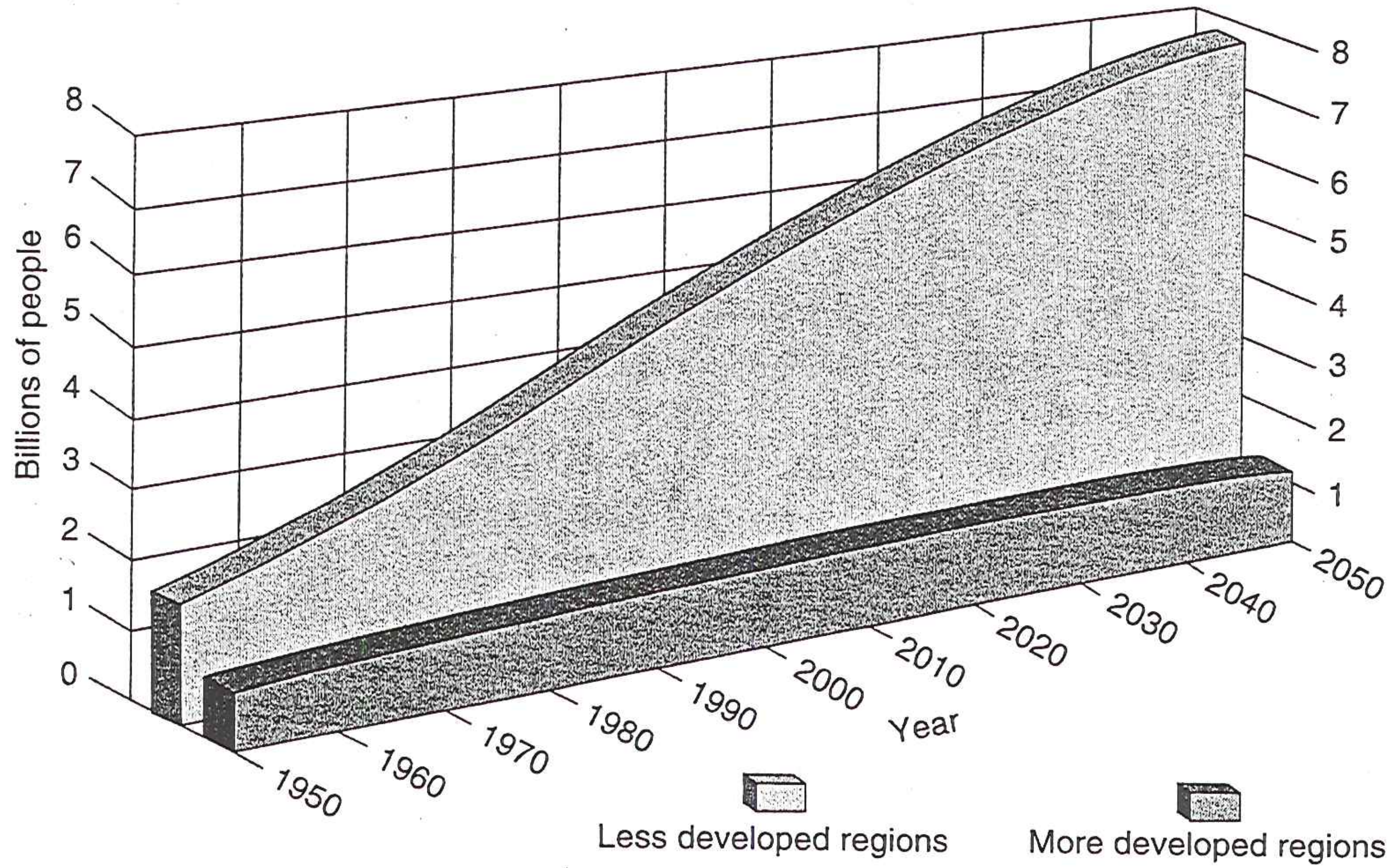


FIGURE 2.1 Historical and projected human population growth in billions for less developed and more developed regions, 1950-2050.
Source: UN (1999). Courtesy of the United Nations.

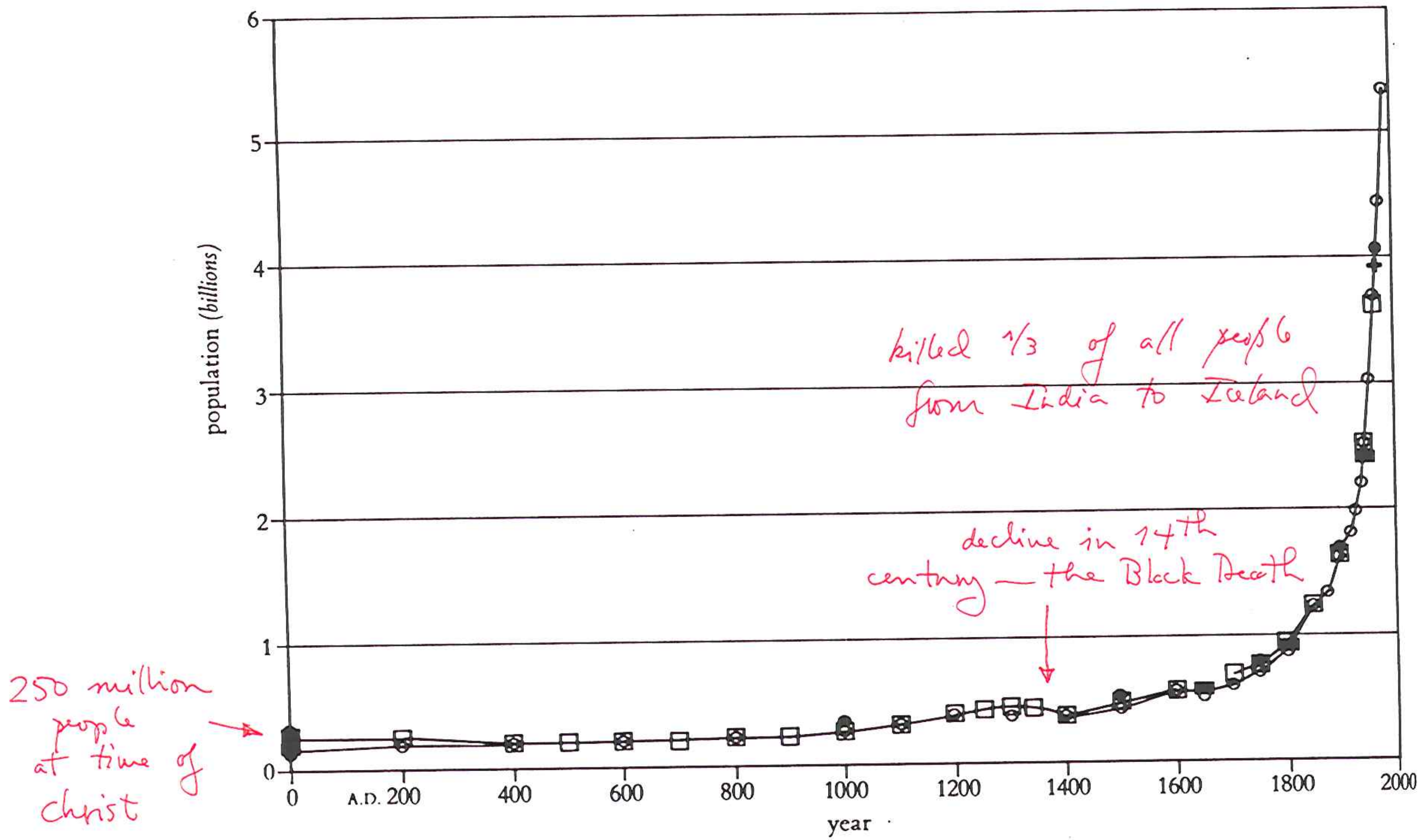


FIGURE 5.3 Estimated human population from A.D. 1 to the present. Different symbols represent estimates from different sources. SOURCE OF DATA: Appendix 2

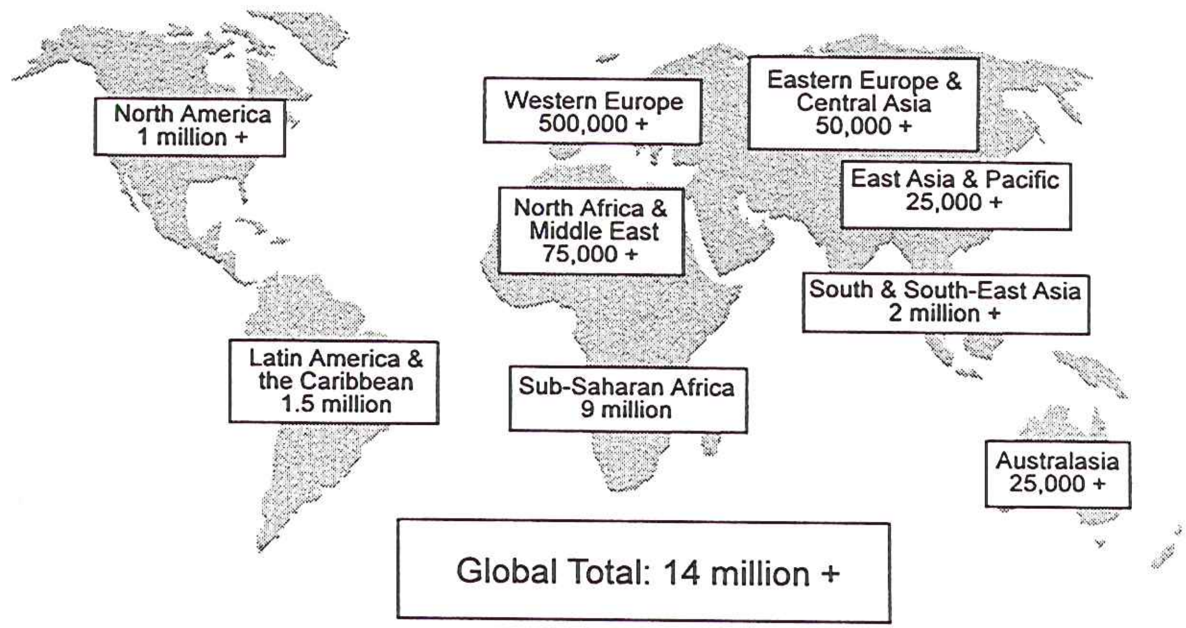


Figure 5.15. Estimated distribution of total adult HIV infections at the end of 1993. (Source: Global Programme on AIDS, World Health Organization; Aggleton et al. 1994)

THE NEW YORK TIMES **INTERNATIONAL** WEDNESDAY, NOVEMBER 26, 1997

New U.N. Estimate Doubles Rate of Spread of AIDS Virus

New York Times
November 26, 1997

31 million people
infected with
HIV or AIDS

UPDATE

A New, Grimmer Portrait of AIDS

The United Nations has revised its estimates of the worldwide spread of H.I.V., the virus that causes AIDS.

	PREVIOUS (1996)	REVISED (1997)
PEOPLE WITH H.I.V. OR AIDS	22.6 million*	**30.6 million**
Sub-Saharan Africa		20.8 million
South and Southeast Asia		6 million
Latin America		1.3 million
North America		860,000
Western Europe		530,000
East Asia and Pacific		440,000
Caribbean		310,000
North Africa, Middle East		210,000
Eastern Europe, Central Asia		150,000
Australia, New Zealand		12,000
NEW INFECTIONS PER YEAR		
Total	3 million	**5.8 million**
Children	350,000	**580,000**
DEATHS PER YEAR		
Total	1.5 million	**2.3 million**
Children	350,000	**440,000**

*No continent-by-continent breakdown available for 1996

Source: United Nations

The New York Times

21 million of
these in
sub-Saharan
Africa

world-wide
infection rate
0.1% per year

AIDS Is Slashing Population Of Africa, U.N. Survey Finds

By YOUSSEF M. IBRAHIM

UNITED NATIONS, Oct. 27 — AIDS is cutting the life expectancy in many African countries and will effectively reduce their populations within the next 10 to 15 years, according to a report to be released on Wednesday by the population division of the United Nations.

The report, part of a world population survey for 1998, says AIDS has achieved pandemic proportions in several of 34 sub-Saharan countries, where at least one in four people is infected with H.I.V., the virus that causes AIDS.

In Botswana, the hardest hit country in sub-Saharan Africa, life expectancy, which stood at 61 years only five years ago, has dropped to 47 and is expected to drop to 41 between 2000 and 2005.

In Zimbabwe, where one of every five adults is infected, the high mortality rate is significantly reducing the country's population and its growth, from 3.3 percent a year between 1980 and 1985 to 1.4 percent now and a projection of less than 1 percent beginning in 2000. Had it not been for the virus, Zimbabwe's population would have been growing at a projected rate of 2.4 percent now.

"Of the 30 million persons in the world currently infected by H.I.V., 26 million, or 86 percent, reside in these 34 countries. In addition, 91 percent of all AIDS deaths in the world have occurred in these 34 countries," the report said.

[Af]rica, experts said, it is changing the demographic profile of the continent, the daily rhythm of life, and the outlook for tens of millions of people.

Experts also stress that AIDS is making its way through large countries like India, China and Brazil, where the huge populations result in a faster spread of disease.

Most affected are people between 10 and 24 years old. Of the estimated 7,000 daily infections around the world, half are occurring in this age bracket, the report said.

Despite the enormity of the problems affecting Africa, attention seems to have shifted from the disease, largely because it seems to have been contained in the advanced industrialized nations.

"I don't think many people are aware of the scale," said Lester Brown, president of World Watch Institute, a nonprofit environmental organization in Washington D.C. "This alters rather dramatically the population trends in Africa. In some countries, as much 20 to 25 percent of the population is H.I.V. positive," he said in a telephone interview today.

"In looking at global epidemics," he added, "one has to go back to the 16th century and the introduction of smallpox in the Aztec population of what is now Mexico to find anything on that scale, and before that, to the bubonic plague in Europe in the 14th century, to see that kind of heavy toll."

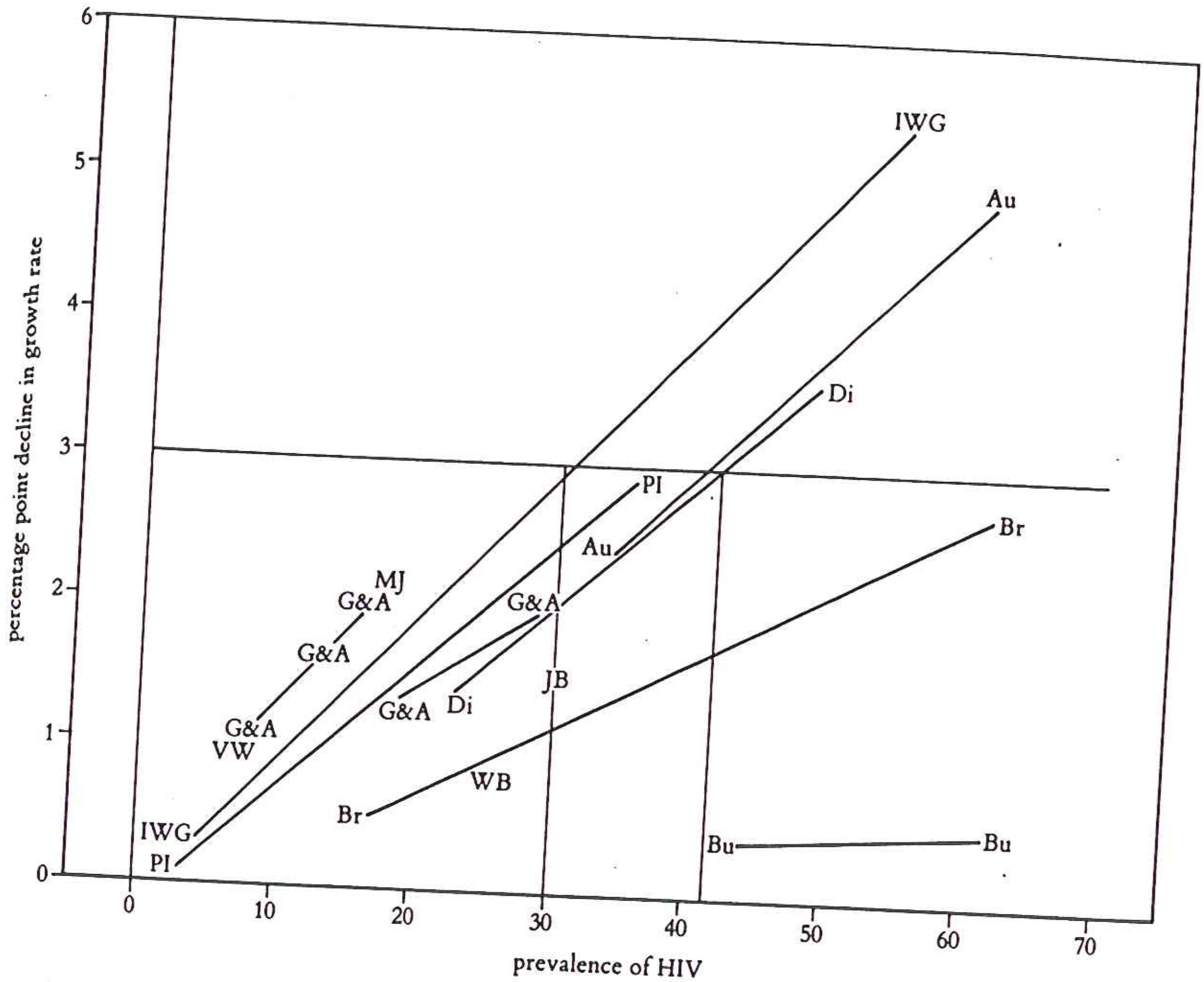


FIGURE 15.1 Estimates of the decrease in the rate of population growth as a function of the adult prevalence of HIV infection. Each set of initials summarizes a result of one study, which is identified by the initials of its authors. When a study considered a range of estimates, the extreme values of HIV prevalence and of reduction in the growth rate are shown as the endpoints of a line segment. For example, the line segment labeled "Bu" in the lower right corner identifies the estimates of a model by Rodolfo A. Bulatao. Different authors defined adult prevalence in different ways; some included one sex only and some included both. SOURCE: Zaba 1994

POLICY FORUM: GLOBAL POPULATION GROWTH

Demographic Consequences of Declining Fertility

John Bongaarts

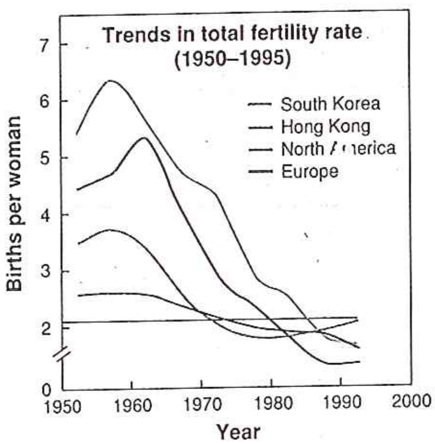
A revolution in reproductive behavior has swept the globe since the 1960s. In the developing countries of Asia, Africa, and Latin America, contraceptive use, once rare, is now widespread and the average number of births per woman has fallen by half, from the traditional six or more to closer to three today. In the industrialized world, fertility has already dropped below two children per woman. This unprecedented development has led the United Nations (UN) to revise downward its latest forecast of world population. As a result, some fear a "population implosion" or claim that the world population explosion is over (*1*).

However, instead of being near the end of an explosion at today's population of 5.9 billion, we are in fact just past its midpoint, according to the newly revised UN projection (*2*). After a record-breaking increase of 2 billion people over the past 25 years, an increase of another 2 billion is projected to occur over the next 25 years and a further expansion to 10.4 billion is expected by 2100. Nearly all of this growth will occur in the developing countries, in which four-fifths of the world's population lives. Despite the plummeting fertility rates, large increases in the populations of Africa, Asia, and Latin America are expected.

These population increases are expected for three reasons. First, the average decline from six to three births per woman (bpw) still leaves fertility about 50% above the two-child rate needed to bring about population stabilization. With more than two surviving children per woman, every generation is larger than the preceding one, and as long as that is the case, population expansion continues.

Second, declines in mortality—historically the main cause of population growth—will almost certainly continue. Higher standards of living, better nutrition, expanded health services, and greater investments in public health measures have increased life expectancy by 50% since 1950, and a further rise is likely. The unhappy exceptions will be mostly in sub-Saharan African countries with severe AIDS epidemics. As more people live longer, there will be more people alive.

The final and most important factor is what demographers call "population momentum." This term refers to the tendency of a population to keep growing even if fertility could immediately be brought to the replacement level of 2.1 bpw, with constant mortality and zero migration. The reason for this growth is a young population age structure, which includes the historically largest generation of women about to enter the childbearing years. These women will produce more than enough births to maintain population growth for decades, even if they each have only two children. Further large increases in the population of the developing world are therefore virtually certain.



SOURCE: ADAPTED FROM (2)

Europe, North America, and Japan face a quite different demographic future. In these countries, the key concerns are aging and potential population decline, because measured fertility has remained below the replacement level since the mid-1970s. Although populations in most developed countries are still growing today because of population momentum, rising life expectancy, or immigration, reductions in population numbers are likely if fertility remains below replacement levels. The UN expects this decline to begin in Europe in 2000 and in Japan in 2005, whereas the populations of the United States, Australia, and New Zealand are expected to grow until at least 2050. For the developed world as a whole, population size is projected to rise slowly until 2025 and then decline, leaving the total in 2050 about the same as today. The proportion of the population over age 65 is expected to rise to 25% in 2050, up from 14% today. This trend will make it increasingly difficult for pay-as-you-go social security systems to meet their obligations to retirees.

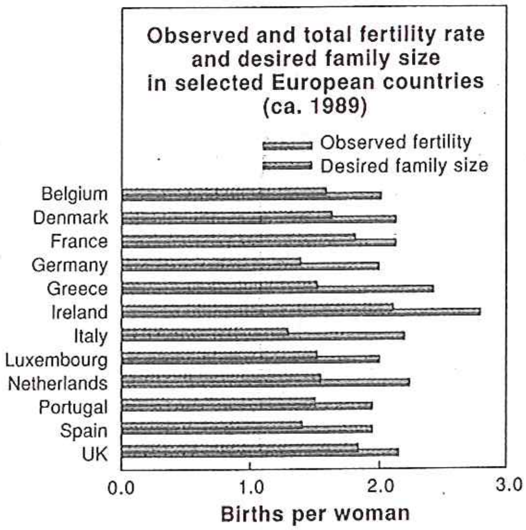
All UN projections are based on assumptions about future trends in fertility, mortality, and migration. The most crucial of these assumptions is that over the next few decades, fertility will move (up or down) in both developed and developing countries to the replacement level of 2.1 bpw and will remain at that level after 2050. This simple assumption ensures zero population growth in the long run. Unfortunately, future population trajectories are highly sensitive to small deviations from replacement. For example, if future fertility were to level off just half a birth above replacement, world population in 2100 would reach 17.5 billion instead of 10.4 billion; conversely, fertility at half a birth below replacement would lead to population decline in the second half of the next century to 5.6 billion in 2100 (*3*). This sensitivity increases the uncertainty of long-range projections, but it is good news for policy-makers: Even modest efforts to change fertility can have a substantial impact on future population size.

The UN's replacement assumption has become increasingly controversial, however, because fertility has dropped below 2.1 bpw (sometimes by a substantial margin) in virtually every industrialized country. Europe's fertility now stands at 1.5 bpw. Similarly, rapidly developing southeast Asian countries have experienced steep declines in birth rates since 1960, leaving fertility today at 1.7 in South Korea and at 1.3 in Hong Kong (see figure at left) A review of this evidence led an Expert Group Meeting, convened by the UN in November 1997, to accept a proposal that the UN abandon the replacement assumption, at least for countries that are now below replacement (*4*). This change, which will be implemented in the forthcoming 1998 projections, should lead to a downward revision of projections in a number of countries. The effects on future world population totals are likely to be fairly small, because the adjustments are modest and they do not apply to the large majority of developing countries.

These adjustments are clearly warranted, but the issue may remain controversial, because in many cases the new future fertility assumptions exceed the current level of fertility. This implies that

The author is in the Policy Research Division, The Population Council, New York, NY 10017, USA. E-mail: Jbongaarts@Popcouncil.org

fertility is assumed to rise between 2000 and 2050 in many industrialized countries. The UN does not provide a detailed justification for this projected fertility trajectory, but there are good reasons to believe that it is reasonable. A key factor putting upward pressure on fertility is that the average desired family size is close to two children, according to surveys in Europe and the United States (typically, couples want one boy and one girl). This finding implies a puzzling discrepancy between expressed preferences and the observed rate of childbearing. This difference in a number of European countries is around 0.5 births per woman (see figure above). It is of course possible that fertility preferences will decline in the future, but they have changed little since the 1970s and they could well remain close to current levels.



Why do fertility preferences exceed measured fertility in most low-fertility societies today? One of the most important causes of this discrepancy is the fact that the most widely reported measure of annual fertility (the so-called total fertility rate) often does not accurately reflect the actual childbearing experiences of women. For example, in France, women who have reached the end of their childbearing years report having 2.1 births on average, which is close to their preferred number, but the annual total fertility rate has been well below replacement since the mid-1970s (*5*). Similar discrepancies exist in many other developed countries. The downward distortion in the total fertility rate is caused by women's decisions to postpone childbearing, which has led to a rise of several years in the mean age at childbearing since 1970. These delays are temporarily contributing to today's baby bust, just as younger childbearing ages in the 1950s temporarily contributed to a baby boom. These distortions can reach as high as 0.4 births per woman, but they are temporary because they exist only while the age at childbearing is rising (*6*). Once women stop deferring births, the distortion disappears and the very low fertility rates observed in the developed world should rise closer to the two children most couples want. This has already happened in the United States, where fertility rose from 1.77 to 2.08 births per woman between 1975 and 1990 as birth deferment stopped. It is therefore plausible to assume that fertility in Europe will not decline further and might even turn upward soon. However, it is unlikely that fertility will rise all the way to the replacement level even in countries where couples continue to want two children, because various constraints (such as divorce, the desire to remain employed, the rising costs of children, and involuntary childlessness) prevent some couples from reaching their desired family size. The most plausible outcome is the pattern now assumed by the UN: a modest rise in fertility to a level somewhat below replacement. If this happens, large population declines will be unlikely.

The policy implications of current trends in reproductive behavior differ sharply between regions. In the already crowded developing world, the addition of several billion more people will hamper ongoing efforts to reduce poverty and achieve sustainable development. Concern over these adverse consequences has provided the principal rationale for past investments in voluntary family planning and reproductive health programs that help couples avoid unwanted childbearing. This vital effort should be strengthened and expanded to include social investments in young people. For example, raising education levels of girls reduces fertility and offsets momentum by delaying the onset of childbearing, in addition to having many direct benefits for the quality of individual lives (*7*).

In the developed world, the potential adverse consequences of prolonged below-replacement fertility have led to extensive discussions but little action. Numerous policy options have been proposed to encourage childbearing: free or subsidized childcare, reduced taxes for families with children, paid parental leaves, subsidized housing for young couples, and so on (*8*). There is unfortunately little useful experience to draw on in assessing the potential effectiveness of various options. In the rare instances where new measures to raise fertility were successfully implemented (such as in Sweden in the late 1980s), it is difficult to disentangle the roles of the specific components in a package of measures. The reluctance of most governments to pursue explicit pronatalist policies is due to a range of factors. These include the awkwardness of promoting domestic pronatalism while subsidizing fertility reduction in the developing world and a reluctance on the part of governments to interfere in the personal matter of reproductive choice. In addition, implementation of effective intervention is expensive, and there is a lack of a feeling of urgency about the problem, especially considering the benefits to the global environment of fewer rich consumers of natural resources. It is quite possible, however, that the population declines expected to become more widespread after 2000 in the developed world will lead to greater concern about their negative consequences and hence to more vigorous action.

POPULATION ESTIMATES (1995) AND PROJECTIONS TO 2050 BY REGION
Population (billions)

	1995	2025	2050
Africa	0.72	1.45	2.05
Asia*	3.47	4.82	5.49
Latin America	0.48	0.69	0.81
Europe	0.73	0.70	0.64
North America	0.30	0.37	0.38
Developing world	4.52	6.82	8.20
Developed world	1.17	1.22	1.16
World	5.69	8.04	9.37

*includes Oceania

References and Notes

1. N. Eberstadt, *The Public Interest* **129**, 3 (1997); B. Wattenberg, "The population explosion is over" *New York Times*, 23 November 1997, p. 61.
2. UN, *World Population Prospects, The 1996 Revision* (UN, New York, 1997).
3. UN, *World Population Projections to 2150* (UN, New York, 1998).
4. UN Population Division, in *Proceedings of Expert Group Meeting on Below Replacement Fertility* (Population Division, UN, 1997, ESA/P/WP.140).
5. Council of Europe, *Recent Demographic Developments in Europe* (Council of Europe Publishing, Strasbourg, France, 1996)
6. J. Bongaarts and G. Feeney, *Pop. Dev. Rev.* **24**, 2 (1998).
7. J. Bongaarts, *Science* **263**, 771 (1994).
8. P. Demeny, in *Proceedings of Expert Group Meeting on Below Replacement Fertility* (Population Division, UN, 1997, ESA/P/WP.140).
9. D. Coleman, in *Europe's Population in the 1990s* (Oxford Univ. Press, 1996).

SOURCE FOR FIGURE ADAPTED FROM (9); SOURCE FOR TABLE ADAPTED FROM (2) disease is manifest in these animals (*5*). Crossing mice lacking follicular dendritic cells or germinal centers (or those lacking chemokine/chemokine receptor combinations) with the autoimmune-prone MRL.Fas^{lpr} mice should help to elucidate the relative contributions of autoantigens, chemokines, and their receptors, and antiapopotic versus proapoptotic signals in the generation of autoreactive B lymphocytes.

The study by William *et al.* (*5*) opens a new vista upon autoimmunity. Their work demonstrates that somatic hypermutation of autoimmune antibodies occurs outside of germinal centers in the autoimmunity-prone MRL.Fas^{lpr} mice. In the absence of the germinal center "checking" mechanism, there is rapid accumulation of high-affinity autoreactive B cells in the T cell zone of lymphoid tissues. The challenge now is to determine how migration to B cell follicles and the formation of germinal centers is prevented in the MRL.Fas^{lpr} mice and whether this is a general phenomenon that will be applicable to other autoantibodies and autoantigens.

References

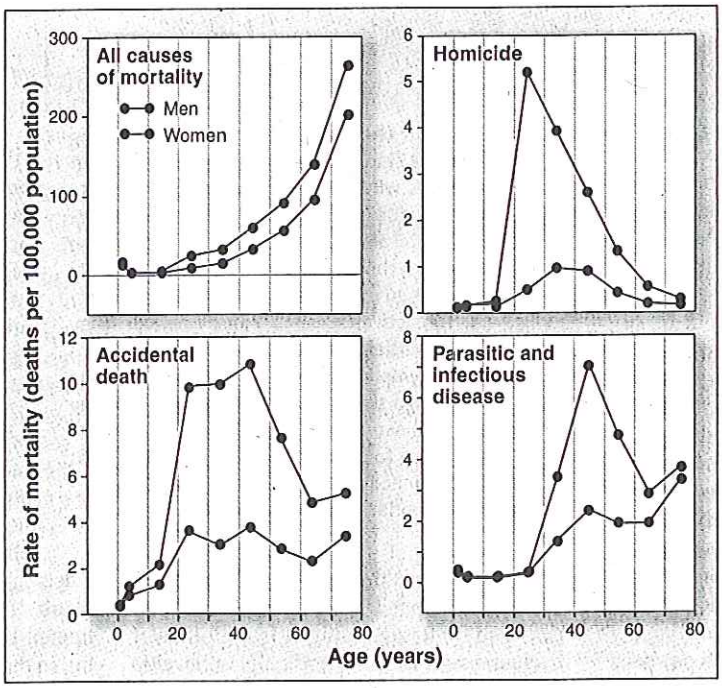
1. Y. Takahashi *et al.*, *Immunity* **14**, 181 (2001).
2. M. J. Shlomchik *et al.*, *Nature* **328**, 805 (1987).
3. G. Kelsoe, *Semin. Immunol.* **8**, 179 (1996).
4. Y. X. Fu, D. D. Chaplin, *Annu. Rev. Immunol.* **17**, 399 (1999).
5. J. William, C. Euler, S. Christensen, M. J. Shlomchik, *Science* **297**, 2066 (2002).
6. U. Storb *et al.*, *Cold Spring Harbor Symp. Quant. Biol.* **64**, 227 (1999).
7. I. Suzuki, P. J. Fink, *Proc. Natl. Acad. Sci. U.S.A.* **97**, 1707 (2000).
8. C. C. Goodnow, J. G. Cyster, *Curr. Biol.* **7**, R219 (1997).
9. K. Reif *et al.*, *Nature* **416**, 94 (2002).
10. J. G. Cyster *et al.*, *Immunol. Rev.* **176**, 181 (2000).
11. A. Masuda, T. Kasajima, *Lab. Invest.* **79**, 849 (1999).
12. Y. Wang *et al.*, *Eur. J. Immunol.* **30**, 2226 (2000).

PERSPECTIVES: ECOLOGY AND EVOLUTION

Sex Differences in Mortality Rate

Ian P. F. Owens

Why do men typically die earlier than women in Westernized societies? The traditional explanation has been that men undertake more risky behaviors. Supporting this risk-prone behavior hypothesis are human demographic data showing that men are consistently more likely to die as a result of motor vehicle accidents, homicide, suicide, or accidents caused by firearms (*1*). Although the death rate through homicide in the United States is more than 10 times that in the United Kingdom and Japan, males are still twice as likely as women to be murdered in all three countries (*1*). The way in which the mortality rate changes with age also supports the risk-prone behavior hypothesis: The rise in accidental and violent death among men coincides precisely with the onset of puberty (see the first figure). On page 2015 of this issue, Moore and Wilson (*2*) propose that male-biased mortality may be caused in part by a greater susceptibility of males to infection by parasites, which in turn may be the result of male-male competition to secure mates and territory.



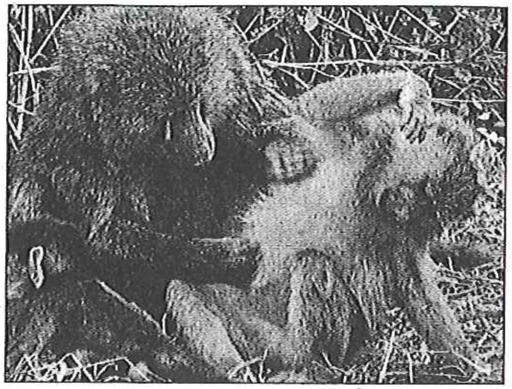
Sex differences in human mortality. The overall mortality rate in males is higher than that in females from puberty onward **(top left)**. The other three graphs show sex differences in mortality rate due to homicide, accidental death, and parasitic and infectious diseases. For all three causes, mortality rate is higher in men than in women, but the timing of the onset of male-biased mortality varies across causes. For death through homicide and accidental causes **(top right, bottom left)**, the increase in male-biased mortality begins immediately after puberty. For death caused by parasitic and infectious diseases **(bottom right)**, the sex difference in mortality rate becomes apparent much later. [Data for 1997 USA population from (*1*) (www.who.int/whois)]

The author is in the Department of Biological Sciences and NERC Centre for Population Biology, Imperial College London, Silwood Park, Ascot, Berkshire SL5 7PY, UK. E-mail: i.owens@ic.ac.uk

Traditionally, male-biased mortality among nonhuman mammals has also been explained in terms of more risky behaviors by males compared with females. Empirical studies of species in which males fight one another for access to females have shown repeatedly that such male-male competition can prove costly in terms of survival. Likewise, comparative studies demonstrate that the species with the greatest male bias in mortality tend to be those species in which male-male competition is the fiercest (*3*).

Moore and Wilson (*2*) now demonstrate that risky behavior by males is not the full explanation for male-biased mortality among mammalian species. They show that sex differences in mortality correlate with differences in susceptibility to parasitism between males and females. In those species where males die younger than females, the males suffer a disproportionately high rate of parasitism. The authors also show that male-biased parasitism is the general rule among mammals, and that it is most extreme in those species where male-male competition for mates is most severe. Taken together, these findings suggest that male-biased mortality occurs not only as a result of death through risky behavior, but also because males are more susceptible to parasitic diseases.

Human demographic data support the idea that parasites are an important determinant of male-biased mortality. Although sex differences in suicide and homicide grab the headlines, males are also more prone to a range of parasitic and infectious diseases (*1*). In the United States, United Kingdom, and Japan, men are approximately twice as vulnerable as women to parasite-induced death. In Kazakhstan and Azerbaijan, where the overall incidence of parasite-induced death is much higher, men



Fight hard, die young. Male-biased mortality is well established in mammalian species. Male savannah baboons have a much higher mortality rate than females and also are much more susceptible to parasitic diseases. The susceptibility of males to parasitism may reflect their greater size or male-male competition for mates and territory (*10*).

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are more than four times as vulnerable to parasite-induced death. Furthermore, the increase in male-biased mortality is not simply associated with puberty, but typically occurs later in life (see the second figure). Together with Moore and Wilson's study of nonhuman mammals, these data suggest that differences between males and females in "immunocompetence"—an organism's all-round ability to avoid the harmful effects of parasites—may underlie the increase in male-biased mortality.

The classic explanation for low immunocompetence in male mammals is that masculinization depends on testosterone, an immunosuppressant (*4*). Long-term comparisons between castrated and "intact" men show that the former outlive the latter by up to 15 years. The life-prolonging effects of castration are proportional to the age at which the operation was performed (*5*). Moreover, because these comparisons have typically been based on institutionalized populations, the elevated rate of mortality among intact males is usually due to infectious diseases rather than violence or accidents.

The exact mechanisms by which testosterone causes immunosuppression are still under investigation. One possibility is that testosterone alters the way in which males allocate resources among competing needs. Males may be unable to mount an effective immune response because they face a trade-off between allocating resources to fending off disease and allocating resources to other activities. The most obvious resource is energy itself and, given the huge number of cells involved in immune defense, it is plausible that a prolonged response would be energetically costly. However, there could be trade-offs with respect to other scarce nutrients, such as carotenoids, which are important not only in many basic metabolic pathways but also for effective operation of the immune system (*6*). Alternatively, trade-offs may occur indirectly—for example, intense metabolic activity could lead to immune system damage caused by the release of free radicals (*7*). It has even been suggested that the reduced immunocompetence of males may be an adaptive response, which minimizes the risk that the male immune system will produce autoantibodies, as happens during autoimmunity (*8*). The relative likelihood of these different mechanisms has not yet been established.

It is worth remembering that the sex differences in susceptibility to parasitism may not reflect "maleness" per se. Indeed, Moore and Wilson (*2*) show that, in species where females are larger than males, it is the females that suffer the greater burden of parasitism. In other words, males are not special, they just tend to be big. This counterintuitive result highlights one of the great difficulties in interpreting results based on the incidence of parasitism: Variations between individuals may be due to differences in exposure to parasites rather than differences in resistance to parasites. Thus, in the context of sex differences in parasitism among mammals, males may simply offer a bigger "target" to parasites because they are big and eat a lot. Again, some human studies support this view, with one showing that women were more vulnerable to some nematode infections simply because they did most of the washing and thereby were more frequently exposed to the infective stage of the parasite (*9*).

The next step is to discover more about the precise physiological mechanisms that lead to the unusually high susceptibility of large mammals to parasitic diseases. Is this susceptibility due to a shortage of energy or a scarcity of nutrients, or is it simply because of a greater exposure to the parasites?

References

1. World Health Organization *World Health Statistics Annual* (2001).
2. S. L. Moore, K. Wilson *Science* **297**, 2015 (2002).
3. D. E. L. Promislow *Proc. R. Soc. London Ser. B* **247**, 203 (1990).
4. M. Zuk, K. A. McKean *Int. J. Parasitol.* **26**, 1009 (1996).
5. J. B. Hamilton, G. E. Mestler, *J. Gerontol.* **24**, 395 (1969).
6. V. Olson, I. P. F. Owens, *Trends Ecol. Evol.* **13**, 510 (1998).
7. T. von Schantz *et al.*, *Proc. R. Soc. London Ser. B* **266**, 1 (1999).
8. L. Raberg *et al.*, *Proc. R. Soc. London Ser. B* **265**, 1637 (1998).
9. D. A. P. Bundy *Parasitol. Today* **4**, 186 (1988).
10. A. M. Bronikowski *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **99**, 9591 (2002).

PERSPECTIVES: ECOLOGY

Quaternary Refugia and Persistence of Biodiversity

Pierre Taberlet and Rachid Cheddadi

Preserving biodiversity represents a daunting challenge for human societies. Ideally conservation policies should be based on sound scientific data, including an understanding of the mechanisms that sustain biodiversity over long periods of time. On page 2044 of this issue, Tzedakis *et al.* illustrate the importance of southern refugia for the persistence of some temperate tree species during the last glacial-interglacial cycles (*1*).

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P. Taberlet is in the Laboratoire de Biologie des Populations d'Altitude, CNRS UMR 5553, Université Joseph Fourier, BP 53, F-38041 Grenoble Cedex 9, France. R. Cheddadi is with the European Pollen Database, CNRS UMR 6116, Centre Universitaire d'Arles, F-13200 Arles, France. E-mail: pierre.taberlet@ujf-grenoble.fr

The Milankovitch theory of climates, relates the glacial-interglacial cycles to changes in Earth's orbital parameters during the Quaternary period (the last two million years). These long-term parameters are orbital eccentricity, obliquity, and precession, with periods of 100,000, 41,000, and 19,000 to 23,000 years, respectively (*2*). Superimposed on the long climatic cycles are short and abrupt climate changes caused by the complex relationships between solar energy, vegetation, and the oceans. For example, in the North Atlantic Ocean, cold climatic cycles of about 10,000 to 15,000 years duration correspond to shifts in the ocean-atmosphere temperature (*3*). These short cycles culminate in huge discharges of icebergs into the North Atlantic Ocean (Heinrich events) (*4*) that are followed by an abrupt shift to a warm climate. Both the long-term and the short-term climatic varia-