Population Growth

An excellent reference: *How Many People Can the Earth Support?* Joel E. Cohen (1995)

Let N_t = number of people living on ⊕ at time t

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

(B_t = no. of births; D_t = no. of deaths)

Exponential growth — suppose that

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

(b = per capita birth rate; d = per capita death rate)

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

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

The solution to the difference equation

$$N_{t+1} = (1+r)N_t \quad \text{is}$$

$$N_t = (1+r)^t N_0 \qquad \star$$

This is of course the familiar compound interest formula. I shall refer to ★ as banker's notation. A scientist or demographer would instead write

$$N_t = N_0 \, e^{t \ln(1+r)}, \quad \text{or}$$

$$\boxed{N_t = N_0 \, e^{\lambda t} \quad \text{where} \quad \lambda = \ln(1+r)}$$

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

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

For example, $\ln(1.05) = 0.04879 \approx 0.05$

scientist's rate ↗ (0.04879) banker's rate ↗ (0.05)

On a log-linear plot:

$$\boxed{\ln N_t = \ln N_0 + \lambda t} \leftarrow r \text{ is the slope}$$

<u>Doubling time</u> (analogous to half life of radioactive or topographic decay)

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

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

Suppose now that the growth rate is a function of time — no longer constant

$$\boxed{N_{t+1} = (1 + r_t) N_t}$$

↑ time-dependent rate

In that case:

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

Taking the logarithm gives:

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

$$= \ln N_0 + \lambda_0 + \lambda_1 + \cdots \lambda_{t-1}$$

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

$$\boxed{N_t = N_0 e^{\lambda_0 + \lambda_1 + \cdots + \lambda_{t-1}}}$$

If all the rates are the same ($\lambda_t = \lambda$) then $\lambda_0 + \lambda_1 + \cdots + \lambda_{t-1} = \lambda t$ and $N_t = N_0 e^{\lambda t}$ as before.

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

It is not $N_{cum} = \sum_t N_t$

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.

The <u>current</u> rate of growth is

$$\lambda_{now} = 0.016 \quad (1.6\% \text{ per year})$$
$$T_{double} = 43 \text{ years}$$

$\lambda_{now} N_{now}$ = 100 million new people added each year.

<u>Current life expectancy</u> T_{now}:

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

<u>Birth rates</u> are also commonly expressed as average number of babies born to a woman in her lifetime (aka <u>fertility rate</u>)

$$\frac{\#\text{ babies}}{\text{woman}} = b_t \cdot \left(1 + \frac{63}{67}\right) \cdot T_t$$

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

$$= (0.026)(1.9)(67)$$

$$= 3.3 \text{ babies/woman} \leftarrow \text{world-wide average}$$

<u>Zero population growth</u> requires

$$b_t = d_t$$

$$b_{now} = 2.6\%$$
$$d_{now} = 1.0\%$$

In a stationary steady-state population:

$$\boxed{b = d = 1/T}$$

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

$$T = \frac{N}{B}$$

N ← total population

B ← no. of people born per year

T ← residence time of a person in population pool

The zero population growth birth rate is not 2 babies/mother because the life expectancy of men is less than that of women:

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

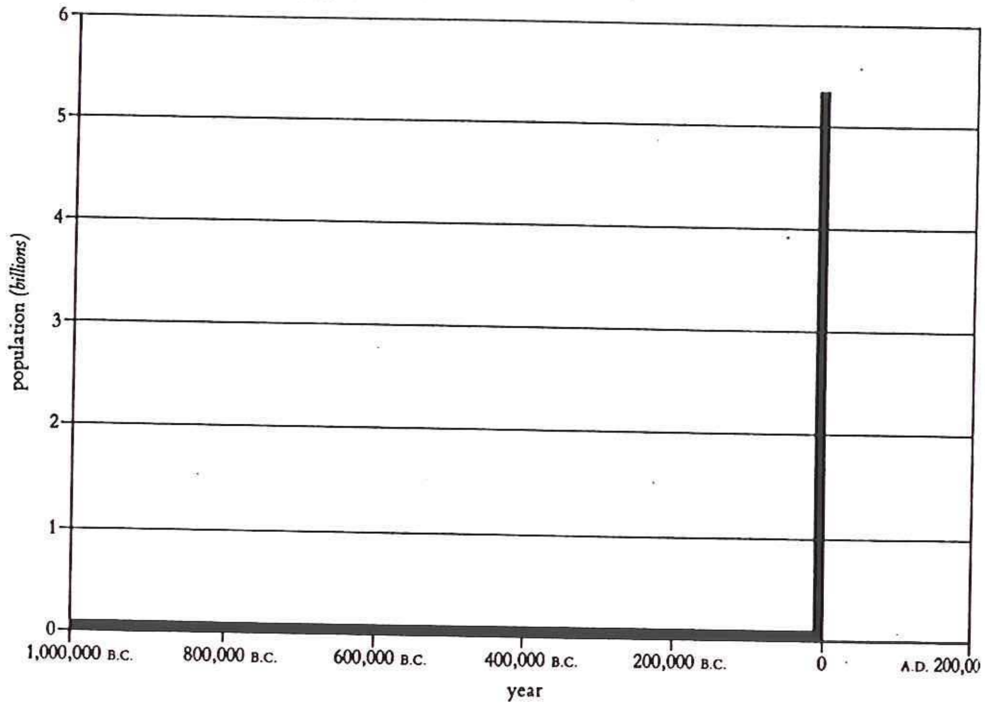


FIGURE 5.1 Estimated human population from a million years ago to the present.
SOURCE OF DATA: Appendix 2

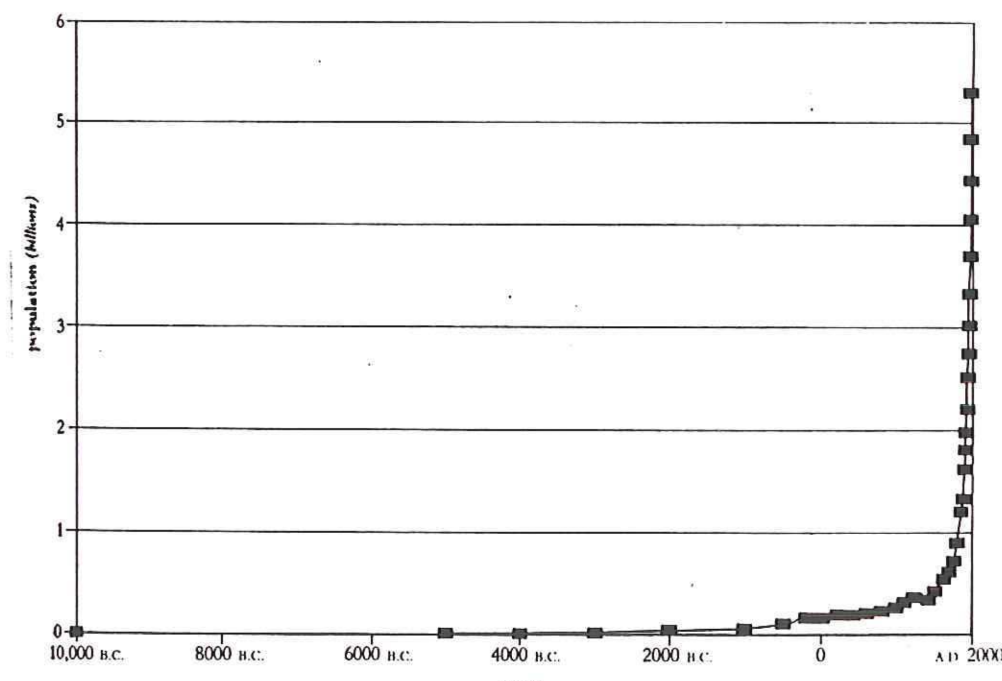


FIGURE 5.2 Estimated human population from the last ice age to the present.
SOURCE OF DATA: Appendix 2

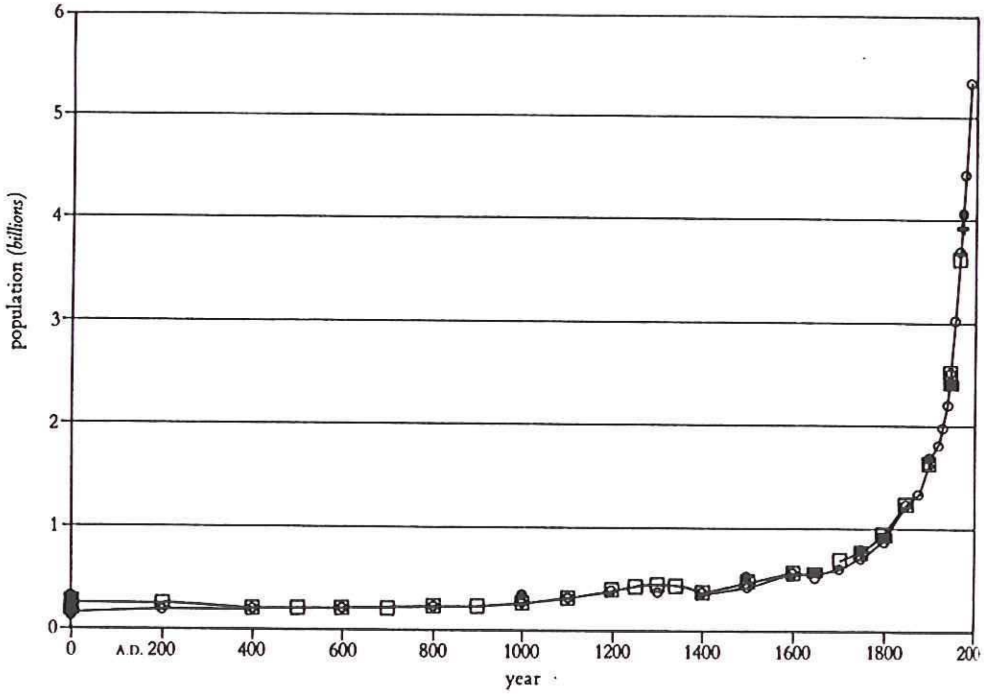


Figure 5.3 Estimated human population from A.D. 1 to the present. Different symbols represent estimates from different sources. Source of data: Appendix 2

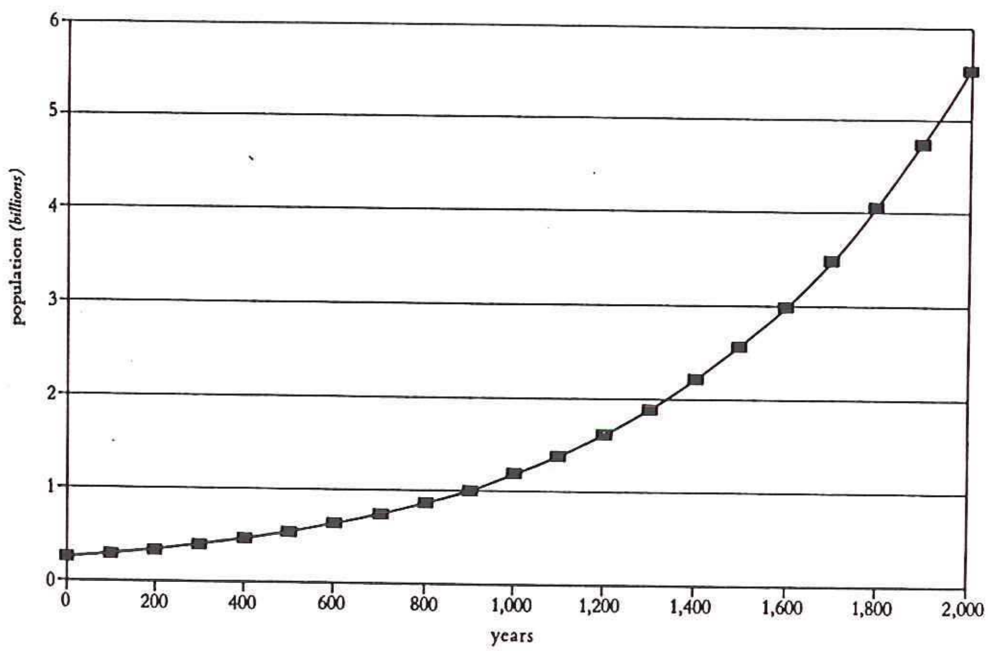


Figure 5.4 Hypothetical population growing exponentially from an initial value of 250 million people at 0.155 percent per year and reaching a population of 5.54 billion after 2,000 years. The population at year t is computed as $2.5 \times 10^8 \times (1.00155)^t$.

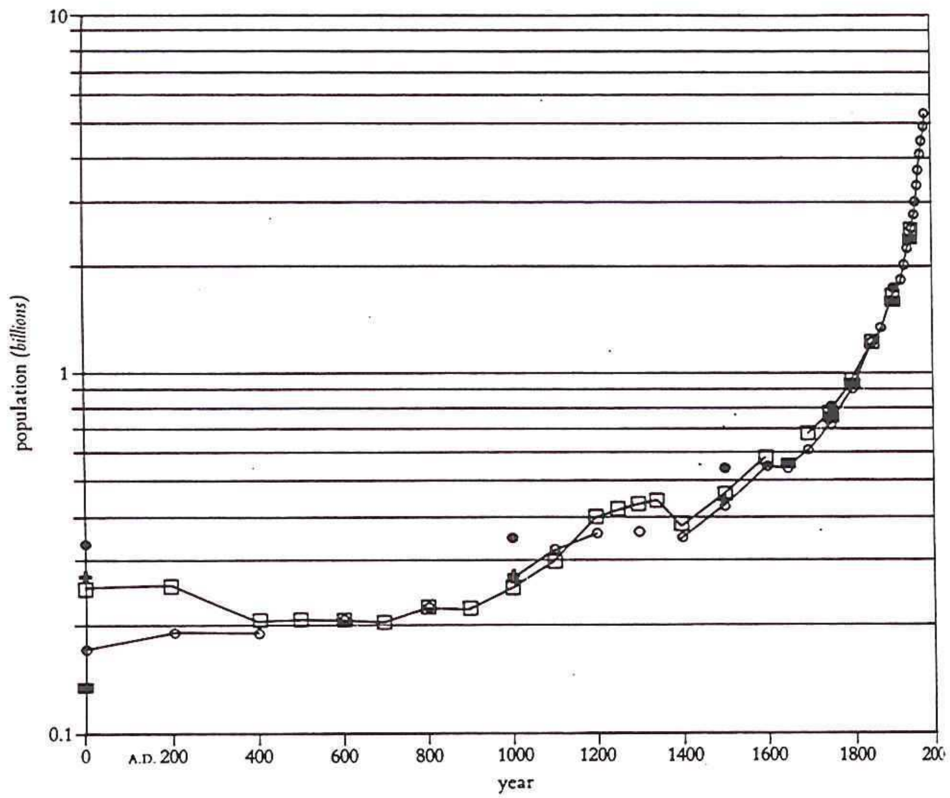


FIGURE 5.12 World population history for the last two millennia, with population plotted on a logarithmic scale. Different symbols represent estimates from different sources. SOURCE OF DATA: Appendix 2

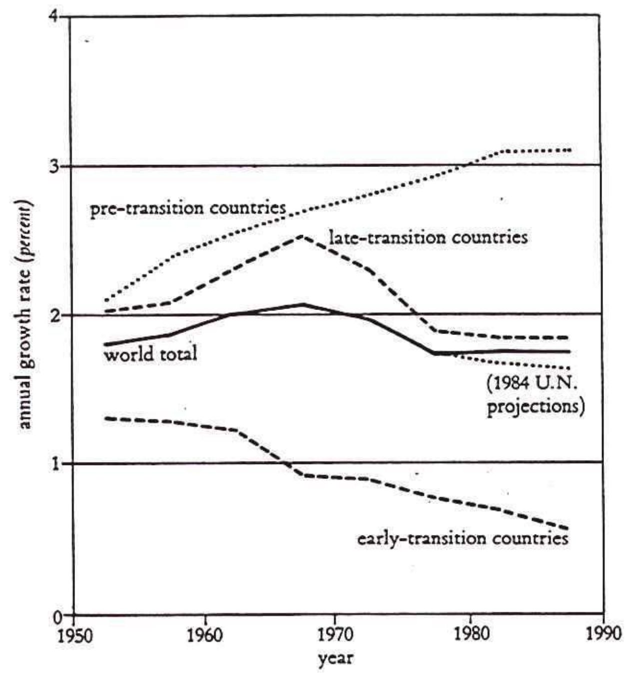


FIGURE 4.2 Global trends in the annual rate of population growth, 1950 to 1990, according to United Nations estimates. For the world total in 1990, the solid line shows the 1990 estimate and the dotted line just below it shows the growth rate projected in 1984; the anticipated decline in the population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

			doubling time *(years)*	
name of evolution	date in the middle	population *(billions)*	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)

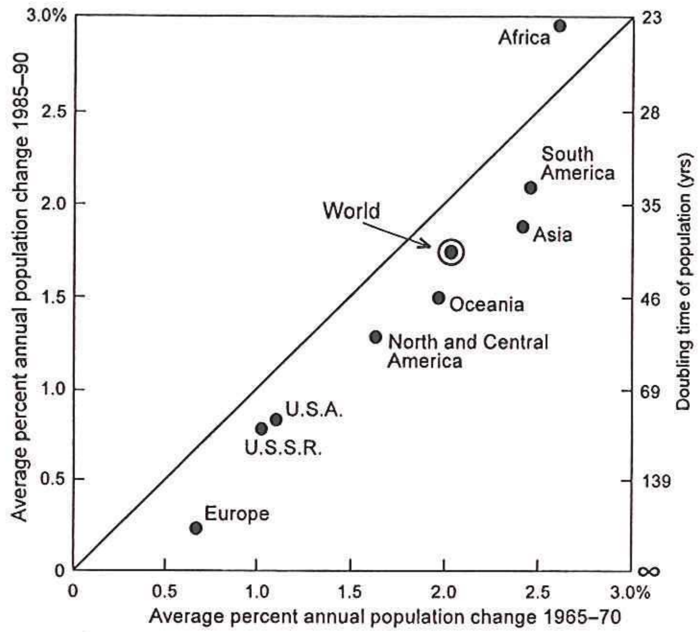


Figure 5.12. Comparison of annual population changes between 1985 and 1990 with those between 1965 and 1970 in several parts of the world.

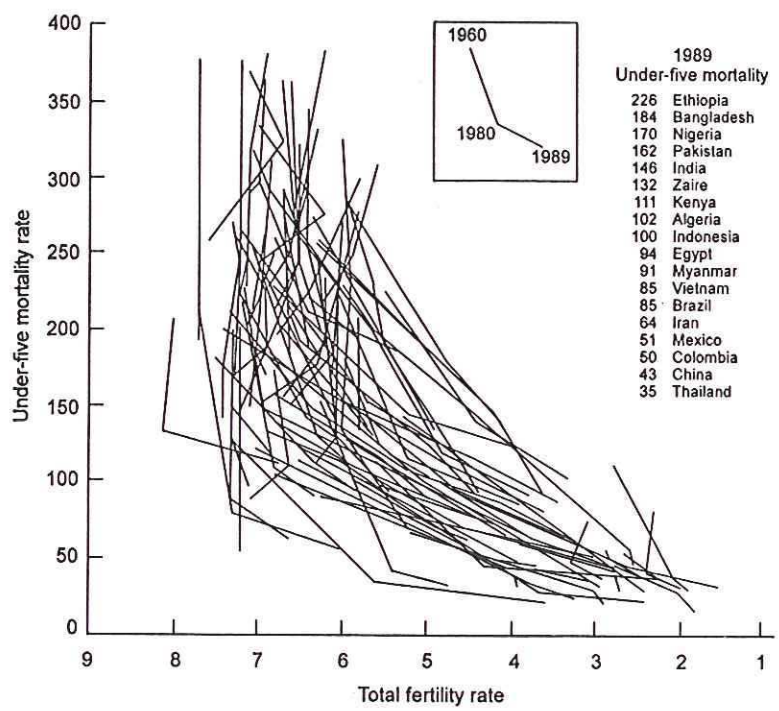


Figure 13.5. Child deaths and child births. Each line on the chart represents, for one developing country, the change in under-five mortality rate (USMR) and total fertility rate (TFR) over the period from 1960 to 1989. The intermediate point on each line represents data for the year 1980. On the right-hand 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)

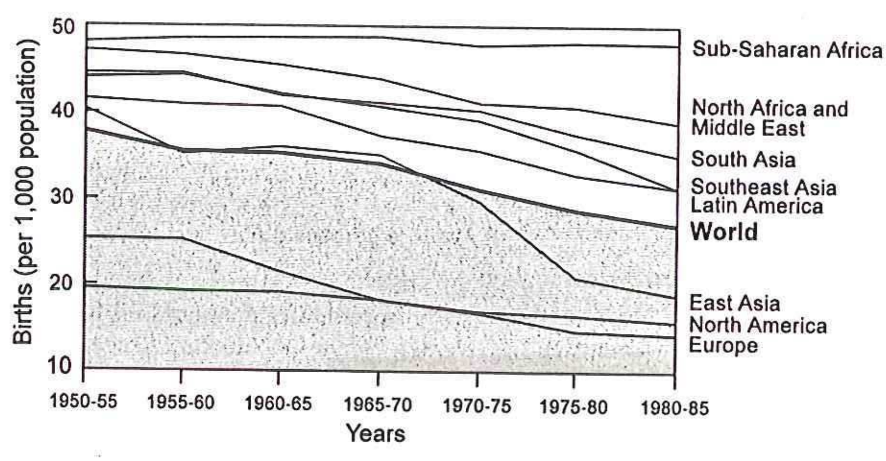
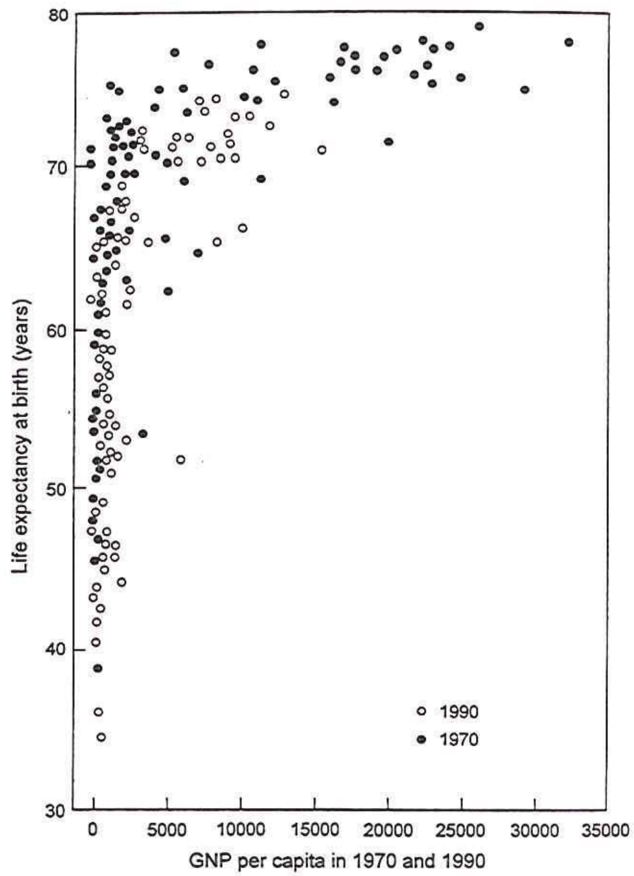


Figure 5.10. Birthrates in regions throughout the world have declined since the end of World War II. The only exceptions to this trend are birthrates in sub-Saharan Africa. Africa could account for nearly a quarter of the world's population by the late twenty-first century. (Caldwell and Caldwell 1990)

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)



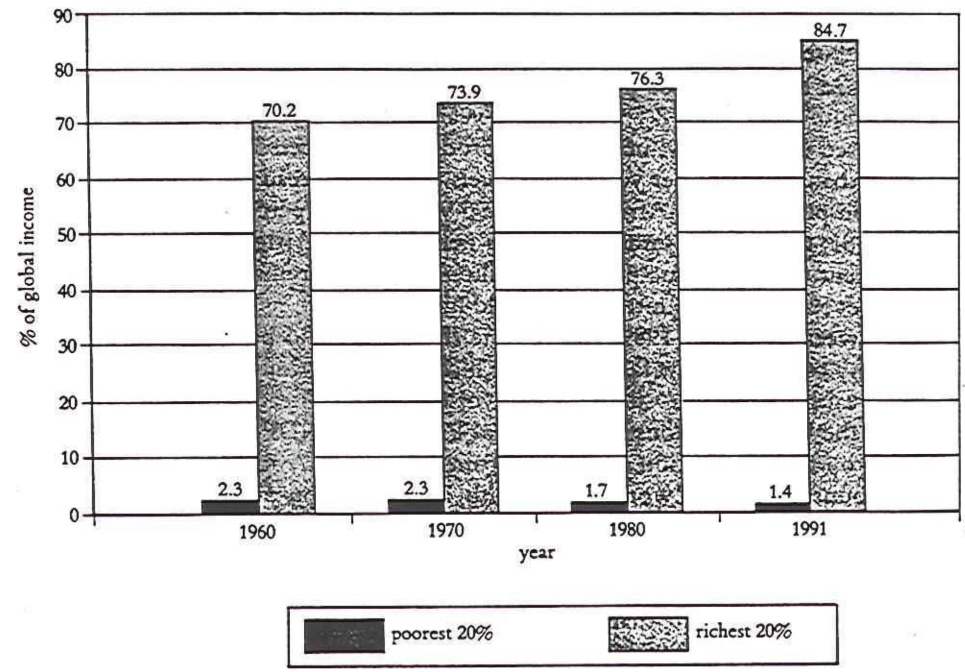


FIGURE 4.1 Fraction of global income received by the poorest 20 percent of people and the richest 20 percent of people from 1960 to 1991, according to the average gross national product per person of different countries. SOURCE: based on United Nations Development Program (1992, pp. 34, 36)

TABLE 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)

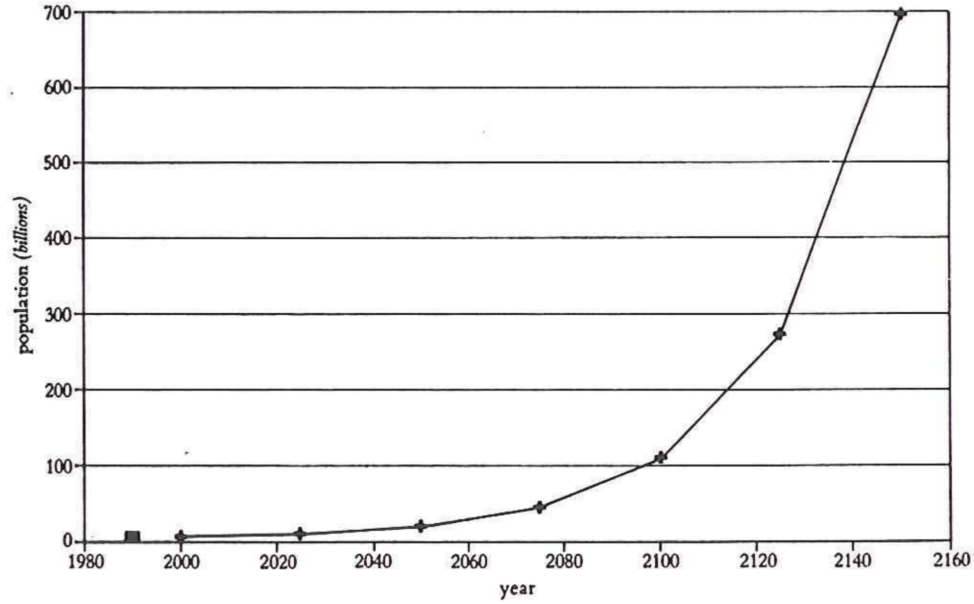


FIGURE 8.1 United Nations' projection of world population, assuming fertility remains constant at its 1990 levels in different regions. SOURCE: original figure drawn according to data of United Nations (1992a)

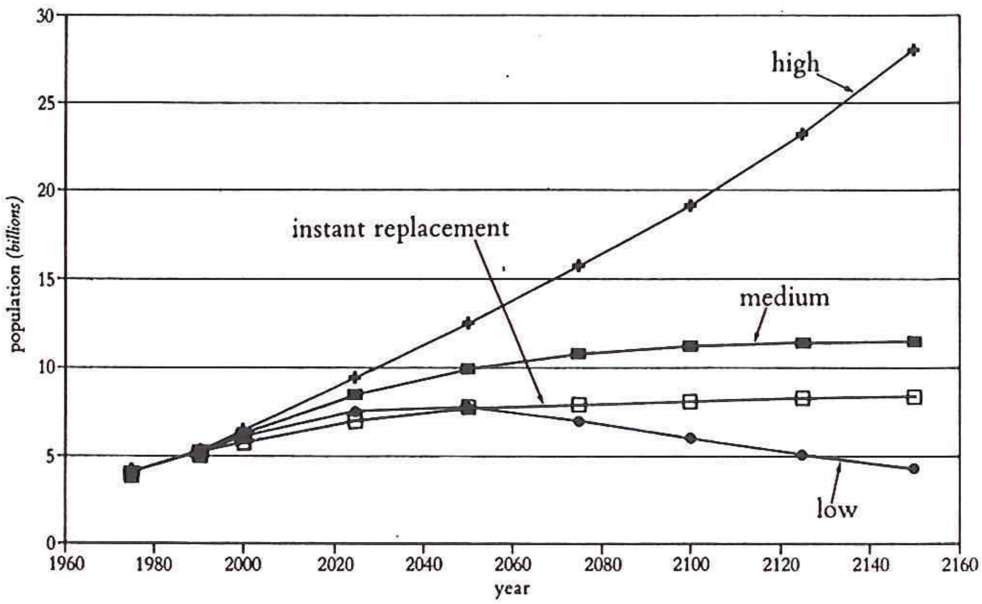
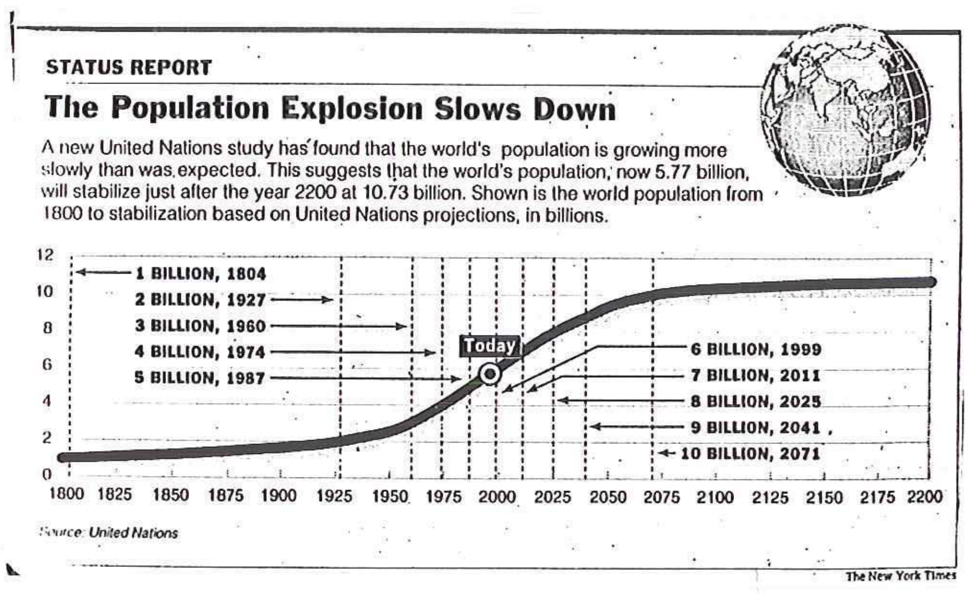


FIGURE 8.2 United Nations' projections of world population, according to high, medium, low and instant-replacement scenarios. SOURCE: original figure drawn according to data of United Nations (1992a)



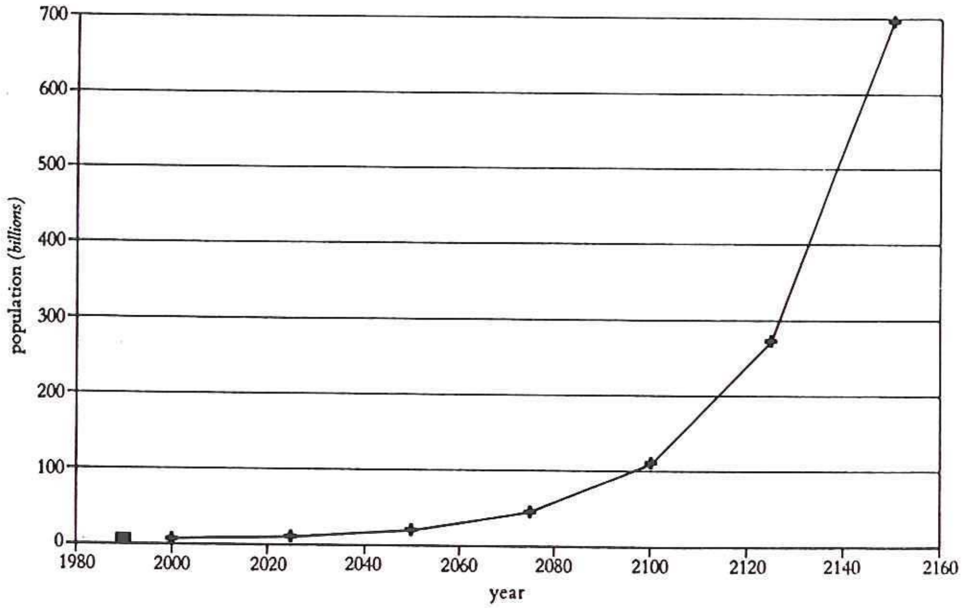


FIGURE 8.1 United Nations' projection of world population, assuming fertility remains constant at its 1990 levels in different regions. SOURCE: original figure drawn according to data of United Nations (1992a)

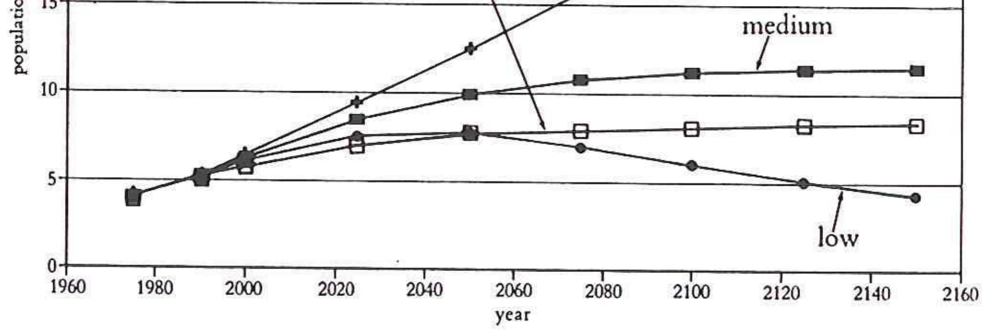


FIGURE 8.2 United Nations' projections of world population, according to high, medium, low and instant-replacement scenarios. SOURCE: original figure drawn according to data of United Nations (1992a)

Estimates of Past Human Population Sizes (Millions)

year (− means B.C.)	Deevey 1960	McEvedy and Jones 1978	Durand 1977		Clark 1977	Biraben 1979	Blaxter 1986[a]	United Nations 1992a	Kremer 1993[b]
			low	high					
−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		Clark 1977	Biraben 1979	Blaxter 1986[a]	United Nations 1992a	Kremer 1993[b]
			low	high					
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)

How many people can the Earth support?

Many estimates focus on resource availability.

Most obvious single limiting resource — food.

If a single resource is limiting:

$$N_{max} = \frac{\text{production / unit area} \times \text{productive area}}{\text{resource requirement per person}}$$

↑ known as Penck's equation (1925)

Consider the denominator — human nutritional requirement:

Units: 1 nutritional calorie = 1 kcal = 4184 J

Basal metabolic rate (BMR): energy intake required to keep body temperature at 98.6°F in a state of no activity.

BMR depends on body weight and other factors, but average is

$$BMR = 1200 \text{ kcal/day} = 5 \text{ MJ/day}$$

For comparison:

$5 \text{ MJ/day} = 5 \cdot 10^6 \text{ J/day} / 86{,}400 \frac{\text{sec}}{\text{day}}$
$= 60$ watts — a dim light bulb.

World-wide average food consumption:

$$2700 \text{ kcal/day} = 2.3 \times BMR$$

UN official definition of undernourished:

$$1700 \text{ kcal/day} = 1.4 \times BMR$$

US consumption:

$$3600 \text{ kcal/day} = 3 \times BMR$$ — leads to obesity.

<u>Total</u> human food consumption:

$$2700 \text{ kcal/day} = 150 \text{ watts}$$ — a bright light bulb

$$\left(150 \frac{W}{\text{person}}\right)\left(6 \cdot 10^9 \text{ people}\right) = 9 \cdot 10^{11} \text{ W}$$

For comparison — heat flow from ⊕ : $4.2 \cdot 10^{13}$ W

human food consumption = 2% of ⊕ heat flow

A well-known estimate of N_{max} was made by Roger Revelle (1976).

He used 2500 kcal/day of grain (rice or wheat) in the denominator of Penck's equation — average in China today.

To estimate the first term in the numerator he made a careful study of <u>potentially</u> arable land.

$$1 \text{ hectare (ha)} = 100\text{ m} \times 100\text{ m}$$
$$= 2.25 \text{ acres}$$
$$\approx 2 \text{ football fields}$$

Total ice-free land on ⊕: $1.3 \cdot 10^{10}$ ha

Revelle felt that $3.8 \cdot 10^9$ ha were potentially arable ≈ 29 % of total.

Final factor in Penck's equation — grain production / ha

Revelle felt that world-wide grain yields could be increased to 2.7 tons / ha

1 ton = 1 "long" ton = 1000 kg = 2200 lb

Finally, we need to know the calorie content of grain. This is basically the same for all plant matter

caloric content of vegetable matter $= 3.5 \text{ kcal/g} = 3.5 \cdot 10^6 \frac{\text{kcal}}{\text{ton}}$

Thus, from Penck's equation

$$N_{max}^{Revelle} = \frac{(3.8 \cdot 10^9 \text{ ha})(2.7 \text{ ton/ha/yr})(3.5 \cdot 10^6 \frac{\text{kcal}}{\text{ton}})}{(2500 \text{ kcal/person/day})(365 \text{ days/year})}$$

= 40 billion people — seven times the current population

Note that this is how many people the Earth could support if each person consumed a Chinese vegetarian diet.

People in the US derive ~2/3 of their 3600 kcal/day from eating <u>meat</u>

To produce 1 kcal of $\left\{ \begin{matrix} \text{beef} \\ \text{chicken} \end{matrix} \right\}$ requires $\left\{ \begin{matrix} 8 \\ 3 \end{matrix} \right\}$ kcal of grain.

Say on average an "inefficiency factor" of 5.

To provide every individual with a US rather than Chinese diet would require

$$3600 \times \left(\frac{1}{3} \text{ vegetable} + 5 \times \frac{2}{3} \text{ meat} \right)$$

$$= 13{,}000 \text{ kcal/day}$$

(5 times as much as a Chinese person)

Then $N_{max} = 8$ billion people.

It all depends on your assumptions.

The world-wide rate of growth of food production (also exponential) is about

3%	=	1% rate of growth of cropland	+	2% rate of growth of crop yield

About twice as large as rate of population growth

Present-day food production in context of global carbon cycle.

Green plants "fix" carbon into organic matter by photosynthesis — highly simplified reaction

$$\underset{\text{in air}}{6\,CO_2} + \underset{\text{in rain or irrigation}}{6\,H_2O} \xrightarrow{\text{sunlight}} \underset{\text{carbohydrate}}{C_6H_{12}O_6} + \underset{\text{oxygen we breathe}}{6\,O_2}$$

Rate of carbon fixation by terrestrial plants (the so-called net primary productivity or NPP):

$$\boxed{NPP = 65 \text{ Gt C / yr}}$$

$$1 \text{ Gt} = 10^9 \text{ tons} = 10^{12} \text{ kg} = 10^{15} \text{ g} = 1 \text{ petagram}$$

The total amount of carbon in the atmosphere is

$$\boxed{760 \text{ Gt C in atmosphere}}$$ ← mostly in CO_2, also methane CH_4

Residence time of a C atom in atmosphere is:

$$\frac{760}{65} = 12 \text{ years}$$

CO_2 is returned to the atmosphere by respiration (mostly by bacteria in the leaf litter)

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

Question #1: What is total rate at which terrestrial plants store solar energy for use by respirers, including humans?

The % of carbohydrate that is carbon (by mass) is

$$\frac{C}{C + H_2 + O} = \frac{12}{12+2+16} = 0.4 \quad (40\%)$$

$$NPP = 6.5 \cdot 10^{10} \frac{\text{tons C}}{\text{yr}} \times \frac{1}{0.4} \frac{\text{tons plant}}{\text{tons C}}$$

$$\times\ 3.5 \cdot 10^{6} \frac{\text{kcal}}{\text{tons plant}} = 5.7 \cdot 10^{17} \frac{\text{kcal}}{\text{yr}}$$

$$\boxed{NPP = 2.4 \cdot 10^{21}\ \text{J/yr} = 7.7 \cdot 10^{13}\ \text{W}}$$

↑ twice the total heat flow from the Earth ($4 \cdot 10^{13}$ W)

Question # 2: What percent of all plant growth (i.e. what percent of NPP) is consumed by humans?

$$2700\ \text{kcal/day} \times 6 \cdot 10^{9}\ \text{people} \times 365\ \text{days/yr}$$

$$= 6 \cdot 10^{15}\ \text{kcal/year} = 2.4 \cdot 10^{19}\ \text{J/yr} = 1\%\ \text{of NPP}.$$

Question #3: What fraction of the sunlight falling on the non-ice covered land is converted into caloric energy stored in biomass by photosynthesis?

The average solar flux at top of ⊕'s atmosphere is:

$256 \text{ kcal/cm}^2\text{/yr}$

Only ~50% gets to the ground — rest is scattered or absorbed by atmosphere or reflected by clouds

$$\underbrace{1.3 \cdot 10^{10} \text{ kcal/ha/yr}}_{\text{sunlight reaching ⊕ surface}} \times \underbrace{1.3 \cdot 10^{10} \text{ ha}}_{\text{non-ice covered land}}$$

$$= 1.7 \cdot 10^{20} \text{ kcal/yr}$$

$$\frac{5.7 \cdot 10^{17} \text{ kcal/yr} \leftarrow NPP}{1.7 \cdot 10^{20} \text{ kcal/yr}} = 0.0034$$

> NPP is 0.34% of solar influx — this is the efficiency of photosynthesis

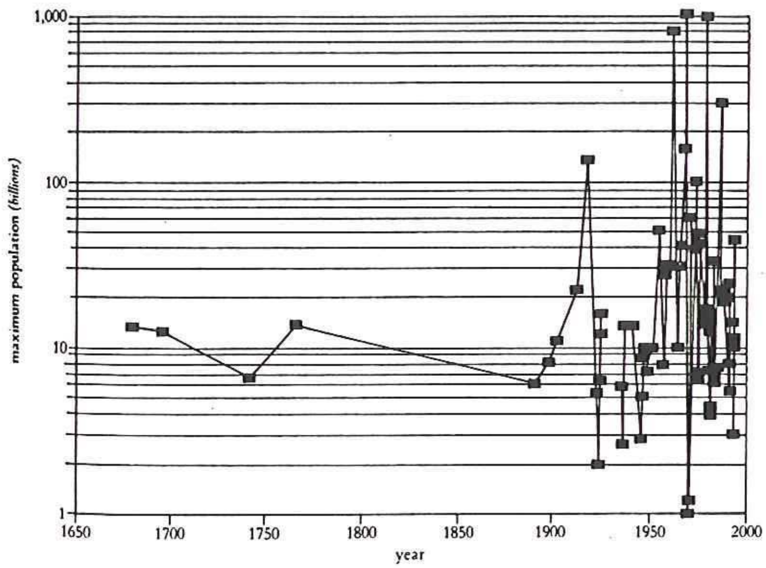


FIGURE 11.1 Estimates of how many people the Earth can support, by the date at which the estimate was made. When an author gave a range of estimates or indicated only an upper bound, the highest number stated is plotted here. The 1964 estimate by J. H. Fremlin would be off the scale and is omitted. SOURCE: Appendix 3

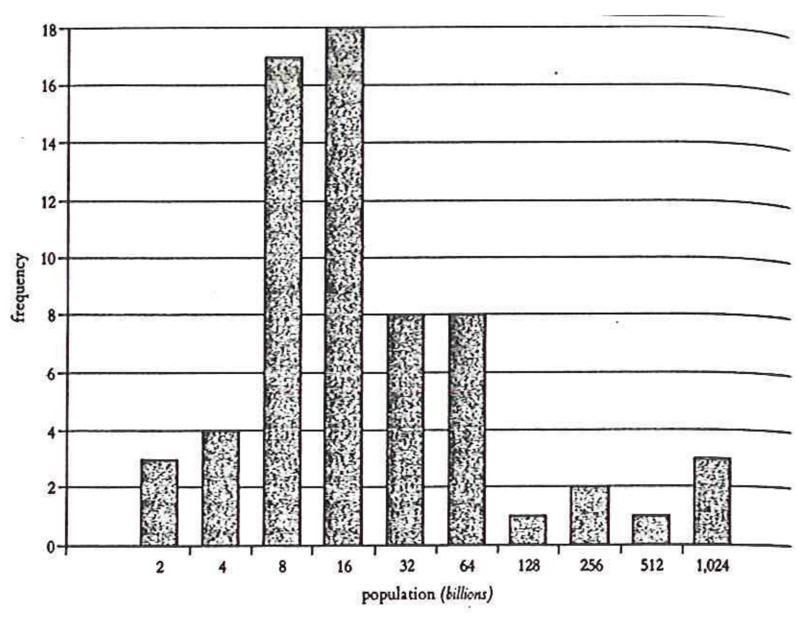


FIGURE 11.2 Frequency distribution of estimates of how many people the Earth can support, based on the highest estimate given by an author. The height of the bar for 4 billion shows the number of estimates greater than the next lower population size shown, that is, 2 billion, and not exceeding 4 billion. Each bar (after the first two) covers a range of population sizes twice as wide as the preceding bar. The 1964 estimate by J. H. Fremlin would be off the scale and is omitted. SOURCE: Appendix 3

Table 5.7. Food Available for Direct Human Consumption (nutritional calories per capita per day)

	1961–63	*1969–71*	*1979–81*	*1984–86*
World total	2,300	2,440	2,600	2,690
Developing countries				
Africa (sub-Saharan)	2,040	2,100	2,140	2,060
Near East/North Africa	2,240	2,390	2,870	3,050
Asia	1,830	2,030	2,260	2,430
Asia[a]	1,970	2,070	2,200	2,280
Latin America	2,380	2,520	2,670	2,700
Low-income countries	1,850	2,020	2,200	2,360
Middle-income countries	2,160	2,340	2,620	2,680
Developed countries	3,060	3,230	3,340	3,380
North America	3,180	3,380	3,510	3,620
Western Europe	3,090	3,230	3,370	3,380
Other developed market economies	2,590	2,810	2,900	2,930
European centrally planned economies	3,140	3,330	3,390	3,410

Source: World Resources, 1990–91.
[a] Does not include China.

Table 5.5. World Land Use, by Region, 1850–1980

Region	*Land Type*	*Area (million hectares)* 1850	*1900*	*1950*	*1980*	*Percent Change 1850–1980*
Ten regions, total	Forests and woodlands	5,919	5,749	5,345	5,007	–15
	Grasslands and pasture	6,350	6,284	6,293	6,299	–1
	Cropland	538	773	1,169	1,501	179
Tropical Africa	Forests and woodlands	1,336	1,306	1,188	1,074	–20
	Grassland and pasture	1,061	1,075	1,130	1,158	9
	Cropland	57	73	136	222	288
North Africa and Middle East	Forests and woodlands	34	30	18	14	–60
	Grassland and pasture	1,119	1,115	1,097	1,060	–5
	Cropland	27	37	66	107	294
North America	Forests and woodlands	971	954	939	942	–3
	Grassland and pasture	571	504	446	447	–22
	Cropland	50	133	206	203	309
Latin America	Forest and woodlands	1,420	1,394	1,273	1,151	–19
	Grassland and pasture	621	634	700	767	23
	Cropland	18	33	87	142	677
China	Forests and woodlands	96	84	69	58	–39
	Grassland and pasture	799	797	793	778	–3
	Cropland	75	89	108	134	79
South Asia	Forests and woodlands	317	299	251	180	–43
	Grassland and pasture	189	189	190	187	–1
	Cropland	71	89	136	210	196
Southeast Asia	Forests and woodlands	252	249	242	235	–7
	Grassland and pasture	123	118	105	92	–25
	Cropland	7	15	35	55	670
Europe	Forests and woodlands	160	156	154	167	4
	Grasslands and pasture	150	142	136	138	8
	Cropland	132	145	152	137	–4
USSR (former)	Forests and woodlands	1,067	1,014	952	941	–12
	Grassland and pasture	1,078	1,078	1,070	1,065	–1
	Cropland	94	147	216	233	147
Pacific developed countries	Forests and woodlands	267	263	258	246	–8
	Grassland and pasture	638	634	625	608	–5
	Cropland	6	14	28	58	841

Source: Repetto 1987.

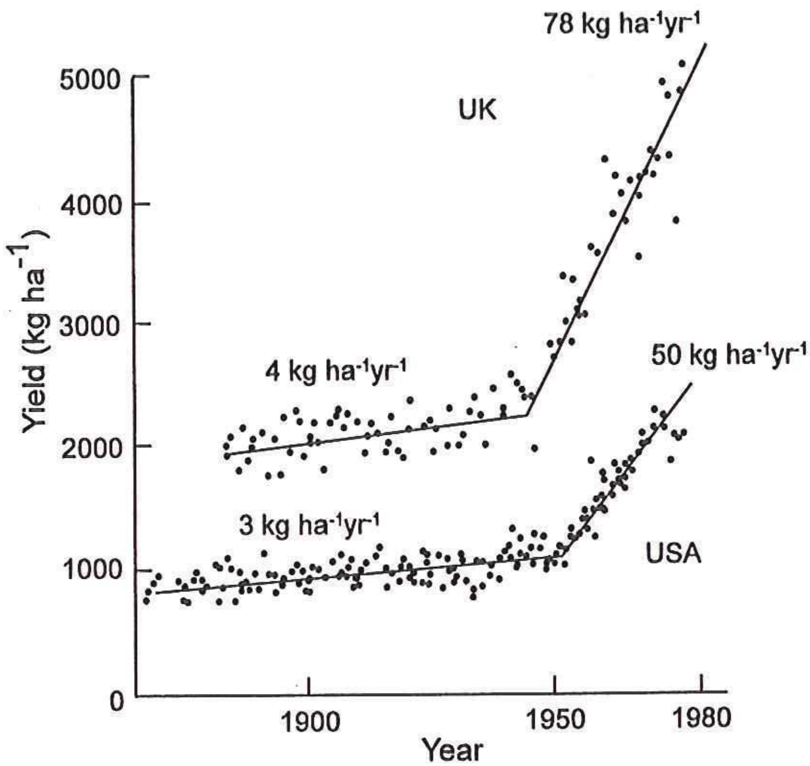


Figure 5.16. Average wheat yields in the United Kingdom during the course of the past century. (Van Keulen and Wolf 1986)

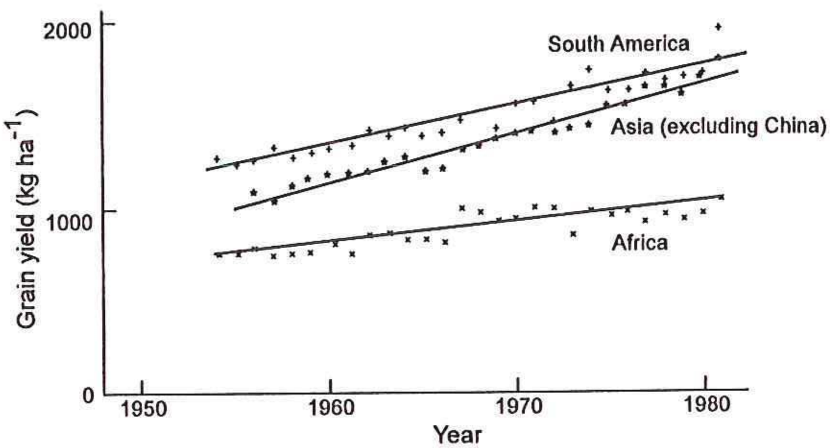
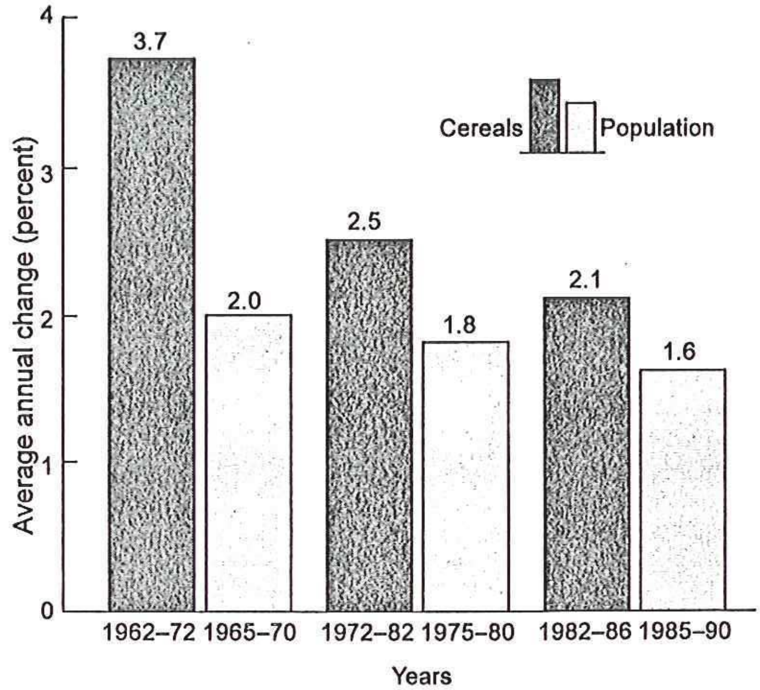
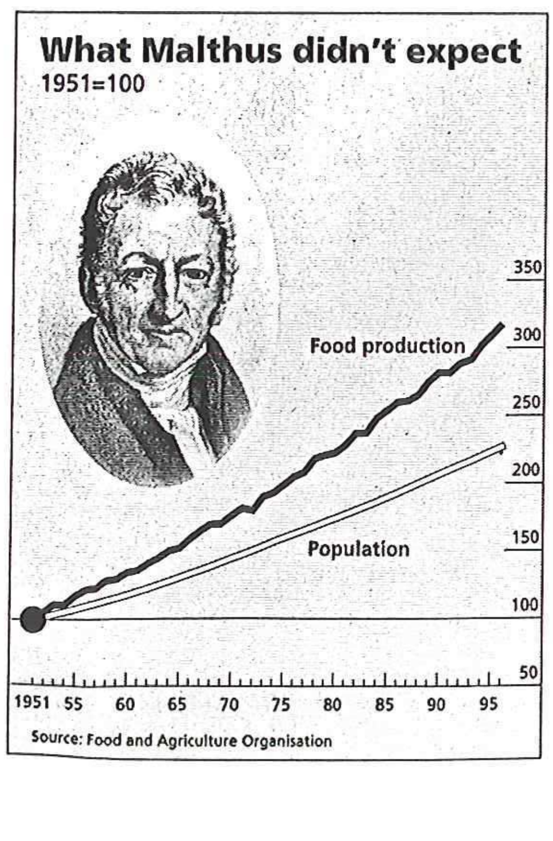


Figure 5.17. Average grain yields from 1954 to 1980 in Africa, Asia, and South America. (Van Keulen and Wolf 1986)

Figure 5.19. World food production is growing faster than world population. The figure shows the annual increase in total production of cereals (darker) and in the world's population (lighter). (Crosson and Rosenberg 1989)





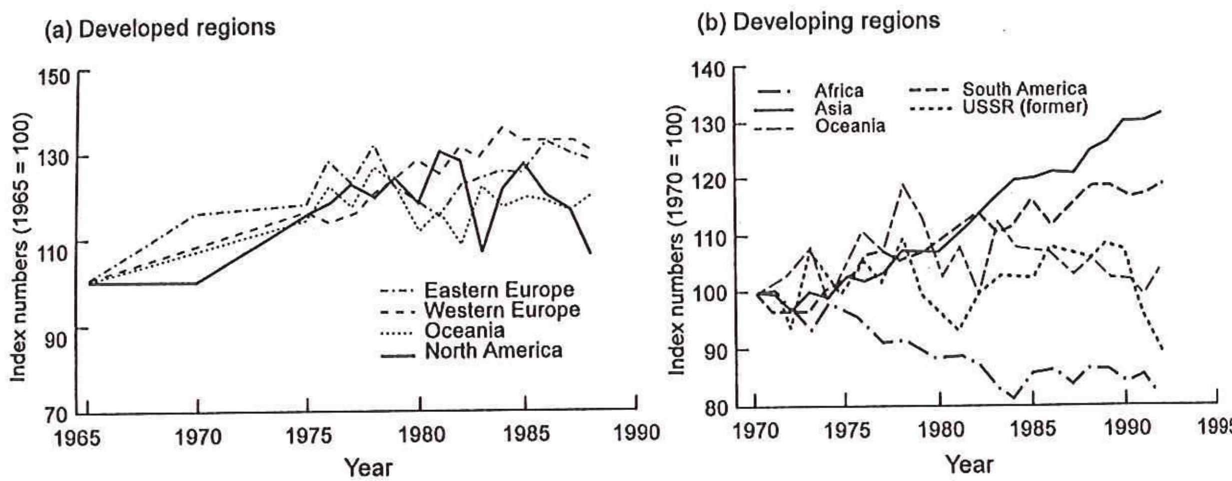
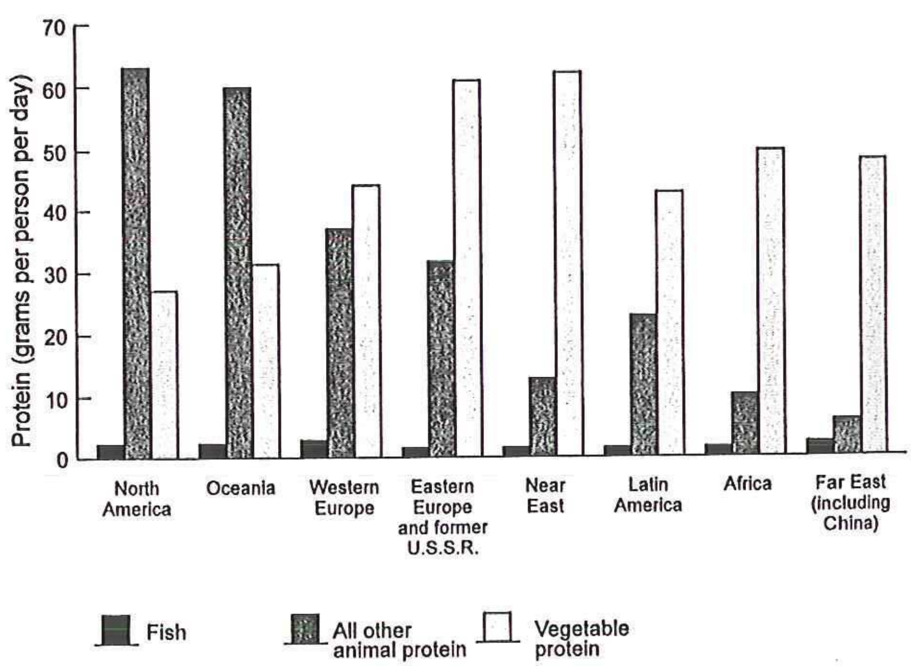


Figure 5.18. Index of per capita food production in the developed and developing regions. (*World Resources 1990–91*, 1990; and *World Resources 1994–95*, 1994)

Figure 5.24. The relatively minor role played by fish in the world's total consumption of protein is apparent when the grams of fish eaten per person per day in various parts of the world (left column in each group) are compared with the consumption of other animal protein (middle column) and vegetable protein (right column). (Holt 1969)



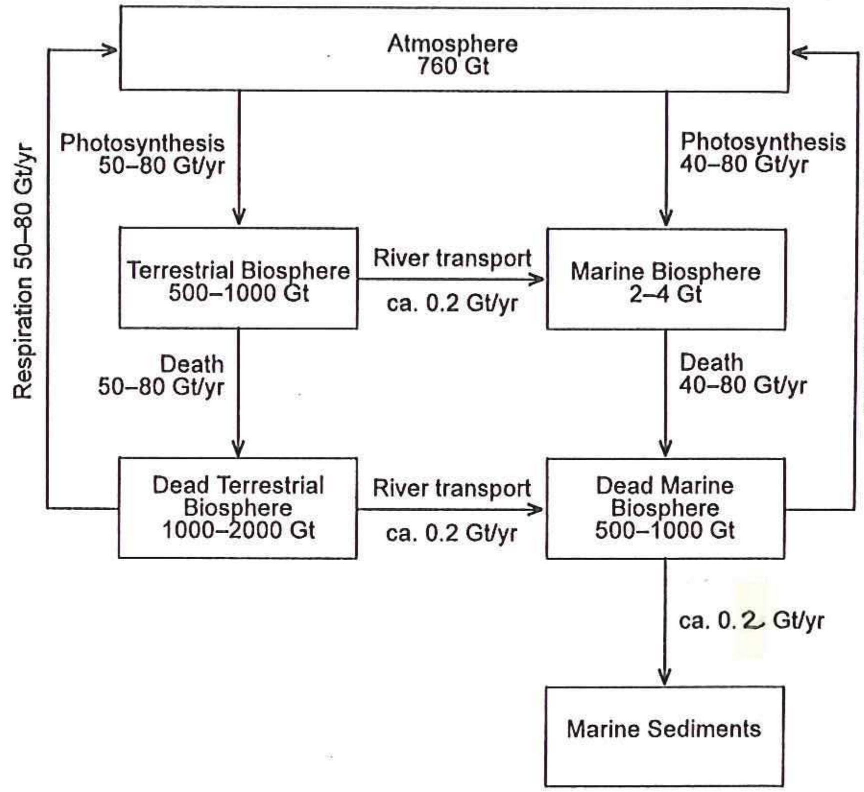
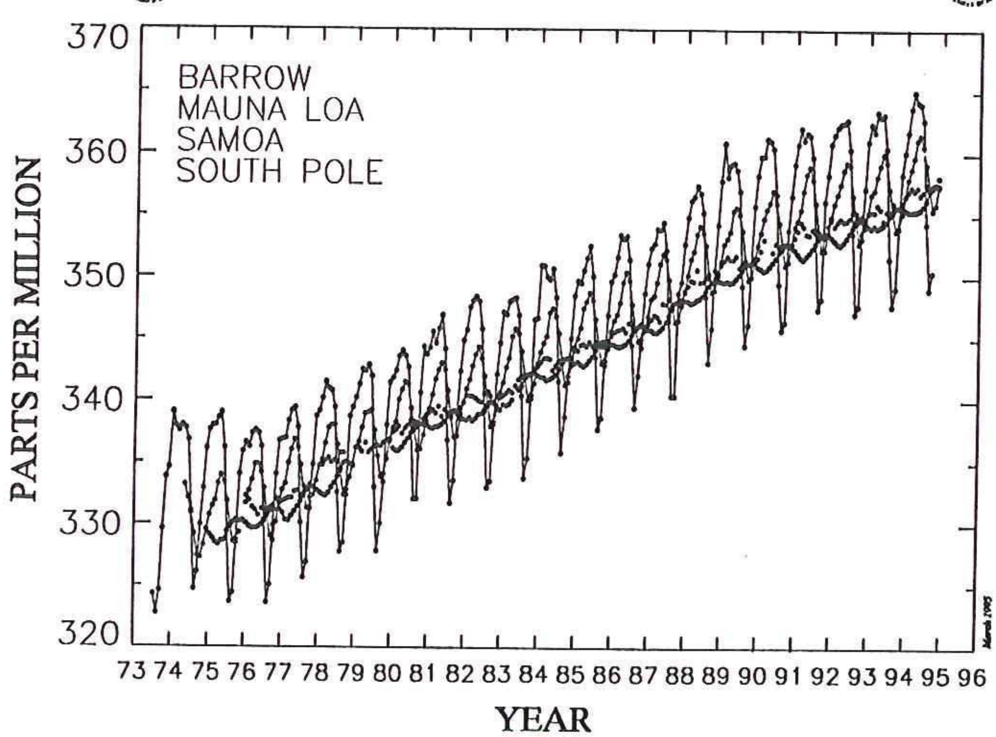


Figure 5.4. The biological parts of the carbon cycle. The carbon content of the several reservoirs is in Gt carbon (1 Gt = 10^{15} gm C). (Data from the compilation of Sundquist 1985)

NOAA/CMDL Monthly Mean Carbon Dioxide



Atmospheric carbon dioxide mixing ratios determined from the continuous monitoring programs at the 4 NOAA/CMDL baseline observatories. Principal Investigator: Pieter Tans, NOAA/CMDL Carbon Cycle Group, Boulder, Colorado, (303) 497-6678, ptans@cmdl.noaa.gov.

Table 5.1. Average Chemical Composition of Organic Matter

Element	*Percentage Composition by Weight* Carbohydrates	Fats	Proteins
O	49.38	17.90	22.4
C	44.44	69.05	51.3
H	6.18	10.00	6.9
P		2.13	0.7
N		0.61	17.8
S		0.31	0.8
Fe			0.1
Total	100.00	100.00	100.00

Source: Rankama and Sahama 1950.

Table 5.2. Average Total Composition of Dehydrated Living Matter

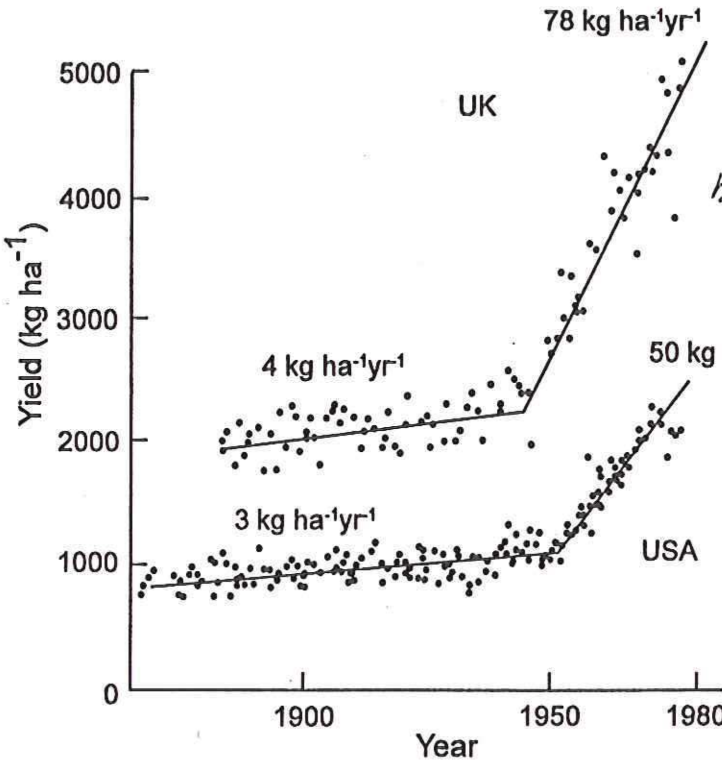
Element	*Percent of Dry Weight* Adult (*Homo sapiens*)	Alfalfa (*Medicago sativa*)
C	48.43	45.37
O	23.70	41.04
N	12.85	3.30
H	6.60	5.54
Ca	3.45	2.31
S	1.60	0.44
P	1.58	0.28
Na	0.65	0.16
K	0.55	0.91
Cl	0.45	0.28
Mg	0.10	0.33
Total	99.96	99.96

Source: Rankama and Sahama 1950.

Table 5.9 Efficiency of Conservation of Light Energy in Various Crops

Crop	*Efficiency of Use of Sunlight (%)*	*Crop*	*Efficiency of Use of Sunlight (%)*
Wheat (Netherlands)	0.35	Soybeans (Canada)	0.18
Wheat (world average)	0.10	Soybeans (world average)	0.10
Corn (United States)	0.35	Sugar cane (Hawaii)	0.95
Corn (world average)	0.17	Sugar cane (Cuba)	0.30
Rice (Japan)	0.42	Sugar beets (Netherlands)	0.56
Rice (world average)	0.18		
Potatoes (United States)	0.31		
Potatoes (world average)	0.17		

Source: Good and Bell 1980.



UK data are offset upward by 1 ton/ha to avoid overlap

Current US yield is ~ 3 tons/ha

Figure 5.16. Average wheat yields in the United Kingdom during the course of the past century. (Van Keulen and Wolf 1986)

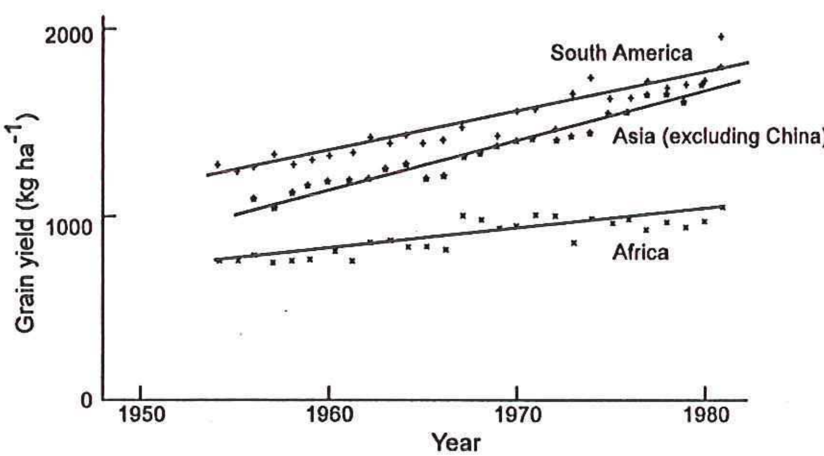


Figure 5.17. Average grain yields from 1954 to 1980 in Africa, Asia, and South America. (Van Keulen and Wolf 1986)