Eating Meat: Evolution, Patterns, and Consequences

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MEAT EATING IS a part of our evolutionary heritage. Recent field studies have shown that chimpanzees, our closest extant primate ancestors, are eager omnivores that supplement their plant-based diet by eating meat. Chimpanzee males hunt small monkeys and share the meat to reinforce social bonds within a group as well as to attract females.[1] Similarly, meat acquisition is still considered a sign of success, and meat sharing still creates personal bonds in most cultures. And our carnivorousness continues to evoke strong emotions, being not only a nearly universal symbol of affluence, well-being, satiety, and contentment but for a minority also an object of scorn and moralistic disapproval.

There is little that is neutral about meat: it has been revered by *bons vivants* of all eras and it is seen as a high-prestige food of choice by America's obese weekend barbecuers of oversized steaks as well as by hundreds of millions of undernourished peasants whose recent migration to the cities of Asia, Africa, and Latin America has brought them closer (physically though not necessarily in terms of income) to the planet's meat-based fast-food outlets. But for millennia meat eating has also been abhorred and renounced by ascetics around the world, be they Dominican *fratres* or Brahmin *sadhus*.[2] For centuries meat was seen as the essential food to energize marching armies and today it is the cornerstone of voguish high-protein diets.[3] This despite the fact we do not have to eat any meat, indeed any animal foodstuffs, in order to lead healthy and active lives and to look forward to generous life spans.[4]

Consider another aspect of meat eating: clouds of inimitably offensive ammonia-laden pigsty smell wafting downwind from feeding factories that contain tens of thousands of animals imprisoned in confined spaces, and leakage of nitrate-laden waste water from lagoons overflowing with slowly fermenting excrement. And more: first the normally herbivorous cattle raised on ground sheep brains and contracting a deadly disease that can be transmitted to humans; then millions of animals stricken by foot and mouth disease purposely killed in a matter of months, their bodies bulldozed onto heaps amid the verdant English countryside and set afire in pyres in a barely controlled panic regarding the disease's ultimate progress.

No wonder that tens of millions of consumers suddenly recoiled in fear and resolved to do without meat in the face of a deadly disease spread by mad cows and infections harbored by dying sheep and virus-stricken poultry. And millions of others, especially the diet-conscious elderly in affluent countries, are following the recommendations for moderate meat intakes shown to be beneficial by epidemiological research. Finally, at the end of the food chain, unprecedented shares of adults and even young children are not merely overweight but definitely obese.

Basic physical dimensions of meat eating are no less fascinating than are its environmental, social, and health impacts. Meat consumption has no bounds of size or species: wild and domesticated animals that are killed and eaten belong to every mammalian family and also include thousands of avian, reptilian, and amphibious species, animals ranging from birds that fit into the palm of a hand to bulls weighing nearly one metric ton. Porcupines and giant rats (*Cricetomys*) are cherished foods in Cameroon (Njiforti 1996); domesticated guinea pigs become temporary pets around the kitchens of Peruvian houses before they are roasted (Charbonneau 1988); Cypriots use illegal mist nets to trap and kill more than 15 million migrating songbirds a year, discarding the unwanted ones and grilling and pickling the prized ones (Cyprus Conservation Foundation 2002); and Congolese pick off meat from the seared scalps of nearly extinct mountain gorillas. And, of course, all modern societies have made mass-produced meat, particularly ground beef, one of the most readily available foodstuffs thanks to the now ubiquitous fast-food eateries and to increasingly generous servings in restaurants.

As it is used in standard nutritional and agricultural writings, the term meat is actually a misnomer. Meat's correct definition is muscles of animals, and muscles are nothing but wet protein tissues.[5] This simple definition would, of course, embrace muscles of all vertebrates (mammals, birds, amphibians, reptiles, and fishes) and invertebrates, whether domesticated or wild. But meat of invertebrates (most of the nutritionally important ones are aquatic species ranging from mussels to scallops) and fishes is usually classed separately. Italians (followed by the French) sweep these meats into the poetically named *frutti di mare* (*fruits de mer*). Including the meat of amphibians and reptiles makes a difference only in quantifying the food consumption of some rural populations in tropical countries where a significant share of the relatively low intake of animal foodstuffs comes from such sources. For people in affluent countries meat means usually only the commercially produced flesh of domesticated (and to a much lesser extent wild) mammals and birds. Its production, supply, and consumption are measured in three basic ways, but, unhelpfully, many statistics leave their particular choice unidentified.

Carcass weight (the method of meat supply reporting preferred by the Food and Agriculture Organization) amounts to as much as 90 percent of live weight in poultry. It averages 74 percent of body mass in American pigs but only 62 percent in beef cattle and 59 percent in dairy steers (Wulf 1999). Carcass cutting yield (the share that ends up as meat) depends on fatness and muscling of the animal as well as on the amount of boneless cuts and on the quantity of fat remaining on retail portions. Retail weight (the method of meat supply reporting preferred by the US Department of Agriculture) may amount to as little as 29 percent of live weight for a very fat beef animal butchered into closely trimmed boneless steaks and roasts and into lean ground beef—or to as much as 62 percent for a heavily muscled market hog turned into bone-in chops and roasts and regular ground pork for sausages. By far the most accurate, but only rarely available, figure is the actual intake at table (retail weight minus cooking and table waste), which can be reliably determined only by expensive household consumption studies such as Japan's National Nutrition Survey (Ministry of Health and Welfare 1995).

Choice of the reporting method makes a substantial difference to average annual aggregates, as indicated by Table 1.[6] Whatever the actual totals may be, humans have always consumed much more than the highly proteinaceous muscles. Some cultures eat (or at least used to before most of their people became more choosy or more squeamish) every internal and external organ, from a bull's testes to his tripe and from a cock's comb to his feet. Internal organs (offal: heart, lungs, kidneys, liver) may or may not be included in reported carcass or retail totals of meat supply. And it is the presence of animal fat, interspersed in muscles or surrounding them, that is

TABLE 1 Differences between live weight, dressed carcass, retail weight, and actual consumption illustrated with the example of US beef

Category	Explanation	Weight (kg)	Percent of live weight
Live weight	Typical US steer	540	100
Carcass weight	Dressed cold carcass	330	61
Saleable retail weight	Bones and fat included	250	46
Edible weight	Boneless steaks and roasts closely trimmed and lean ground meat	205	38
Actually consumed	Edible weight minus cooking and table waste	185	34

SOURCES: Typical share and total weights from Wulf (1999) and USDA (2002a).

responsible for the high energy density of some meat cuts, for their palatability, and for the feeling of satiety that follows eating greasy meat.[7] Craving of this sensation drove our ancestors to kill animals many times their size, as those huge and dangerous megaherbivores (mammoths above all) were walking repositories of fat compared to nonthreatening, abundant, but almost perfectly lean lagomorphs (hares, rabbits). And, 15,000 years later, the very same craving is being exploited every day by the now global hamburger and pizza chains where the icons of fast food usually provide about 50 percent of their food energy from fat.

All of this, as already alluded to in these opening paragraphs, comes at a rather high price, and I will have much to say about the diverse and unwelcome effects of rising meat consumption in the modern world. But the discussion to follow is not an ideological tractate against carnivorousness but rather a careful evaluation of meat's roles in human diets and the environmental and health consequences of its production and consumption. As a result, this essay will displease both the militant vegans who eschew even milk and dairy products, energetically the most efficient of all animal foods, and those who believe that consuming annually a mass of red meat equivalent to twice one's body weight is a mark of an ideal world. There is no doubt that humans are a naturally omnivorous species whose diet (except among the overwhelmingly carnivorous Inuit) has been always dominated by plant foods supplemented by varying, but often fairly substantial shares of meat. Strict human vegetarianism is not a natural choice but a culturally induced adaptation.

At the same time, there is also no doubt that current rates of meat eating in affluent societies are excessive when judged from both environmental and health perspectives. Moreover, their simple extension to a large part of the modernizing world would make all the attendant problems only worse. In reviewing these realities I will first follow the evolutionary sequence, from meat-eating primates to recent dietary patterns, and then detail agricultural, environmental, and health costs of meat production and consumption. More efficient feeding and better environmental management can go only so far in reducing the negative impacts of high meat consumption: if meat is to claim a decidedly positive role in food production and in healthy diets, then its per capita intakes should be reduced from the highest rates now prevailing throughout the affluent world, and the prevailing ways of its production should be reformed.

Evolutionary heritage and preagricultural meat consumption

Evidence for hominid and early human omnivory is rich and indisputable (Kiple 2000; Larsen 2000; Wing 2000; Stanford and Bunn 2001). No foraging society, especially not those in environments subject to pronounced seasonal fluctuations of biomass production, could afford to ignore animal foods. Archeological excavations suggest that meat eating was on the rise some 1.5 million years ago, but because of the unimpressive physical endowment of early humans (smaller and less muscled than modern adults) and the absence of effective weapons, it is almost certain that our earliest ancestors were much better scavengers than hunters (Blumenschine and Cavallo 1992). Large predators of their African homeland (above all lions and leopards) often left behind partially eaten herbivore carcasses, and this meat, or at least the nutritious bone marrow, could be reached by alert and enterprising early humans before it was claimed by vultures and hyenas.

The foraging and scavenging habits of early hominids had to be very similar to the food acquisition of their primate ancestors (Whiten and Widdowson 1991)—and we now know beyond any doubt that hunting for meat has an important place, both nutritionally and socially, in the lives of both chimpanzee species (*Pan troglodytes* and *Pan paniscus*), and hence also in the evolution of Pliocene hominids (Stanford 1996, 1998, 1999). Average consumption of meat among the studied chimpanzee groups, which hunt mostly colobus monkeys and a few other, smaller species, is between 4 and 11 kg a year per capita. In proportion to body mass most early human societies consumed at least that much and many ate a lot more. Excavated evidence demonstrates that meat scavenged from the kills by large carnivores began to be augmented by deliberate hunting perhaps as early as 700,000 years ago. We will never be able to reconstruct reliably all those diverse and changing patterns of pre-Paleolithic nutrition, but the much more abundant Paleolithic record leaves no doubt about the extent and intensity of hunting in some environments.

Controlled use of fire—perhaps as early as nearly half a million years ago, but for certain about 250,000 years ago (Goudsblom 1992)—enlarged the meat-eating opportunities as it increased food intakes. Meat was made more palatable through searing and roasting, and smoking preserved it for later consumption. Moreover, the increased food-energy availability achieved by cooking previously unpalatable plant materials made it possible to engage more frequently in risky hunting (Wrangham et al. 1999). Every animal, from armadillos to zebras, was hunted but, as already noted, megaherbivores were always preferred. This more risky, indeed often fatal, choice has obvious energetic explanations.

While all wild meat is an excellent source of protein, nearly all smaller species contain very little fat and hence have very low energy density: monkeys, hares, rabbits, and small deer have only 1,200–1,500 kcal/kg, or only 30–40 percent of the average energy density of grains, and less than 5 percent fat.[8] In addition, small animals are often quite elusive: rodents live underground, lagomorphs are superb runners, most small mammals in the tropical rain forest are arboreal or nocturnal (or both). Consequently, hunting of small mammals may have returned as little as two to three times as much energy as invested in the pursuit, and in many hunts there was no net energy gain.

In contrast, megaherbivores do not have just a larger body mass, they also contain much more fat and hence their energy density may be more than twice as high as that of small species. A single mammoth thus provided as much edible energy as 100 large deer, and a small bison was easily equal to more than 200 rabbits. Group hunting of these animals yielded 30–50 times as much energy as was invested in their killing (only near-shore whaling was more rewarding, with the carcass yielding as much as 2,000 times the energy spent in the hunt). Moreover, these megaherbivores could be killed without weapons by well-planned and skillfully executed stampeding over cliffs to provide large caches of meat (Frison 1987). Such Upper Paleolithic sites as the French Solutré (with its remains of more than 100,000 horses) and the Moravian Předmostí (Howell 1966) make it clear that some preagricultural diets derived as much as 80 percent of all food energy, and an even larger share of protein, from meat.

Still, it seems improbable that hunting of large herbivores by small populations of Ice Age foragers could have been so intense as to bring about the relatively rapid and continent-wide disappearance of most large grazing animals from preagricultural landscapes. But Alroy's (2001) ecologically realistic simulation of the end-Pleistocene megafaunal extinction in North America demonstrates that even a low population growth rate and a low hunting intensity would have made anthropogenic extinction of megaherbivores inevitable, and his model correctly predicts the terminal fate of 32 out of 41 megafaunal Ice Age species.

But carnivorousness has done more than provide a high-quality substitute for plant foods. Stanford (1999) concluded, on the basis of his research on chimpanzees, that the origins of human intelligence are linked to meat, not because of its nutritional qualities but because of the cognitive abilities that were needed for the strategic sharing of the meat within the group: the intellect needed for strategic sharing of meat was one of the factors behind the expansion of the human brain. And another theory posits that human carnivorousness that progressed far beyond the opportunistic hunting or capture of smaller animals may have directly energized the process of encephalization. The average human encephalization quotient (actual/expected brain mass for body weight) is slightly over 6, compared to values between 2.0 and 3.5 for hominids and primates (Foley and Lee 1991).

The expensive-tissue hypothesis and considerations of practical satisfaction of daily protein requirements make it clear that the relatively high dependence on meat was a matter of physiological necessity. The hypothesis was devised to explain the fact that although human brains are much larger than primate brains—at about 350 g the neonate brain is twice as large as that of a newborn chimpanzee, and by the age of five it becomes more than three times as massive as the brain of the closest primate species (Foley and Lee 1991)—we do not have more metabolically expensive tissues (i.e., internal organs and muscles) than would be expected for a primate of our size. This discrepancy led Aiello and Wheeler (1995) to argue that the only way to support larger brains without raising the overall metabolic rate was to reduce the size of another major metabolic organ. With relatively little room left to reduce the mass of liver, heart, and kidneys, the gastrointestinal tract is the only metabolically expensive tissue whose size can vary substantially depending on the dominant diet.

Obligatory herbivores subsisting on phytomass that combines low energy density with poor digestibility require relatively large gastrointestinal tracts to process large amounts of feed. Voluminous and elaborated fermenting chambers of folivorous ruminants are well known,[9] but the extreme examples are koalas (*Phascolarctos cinereus*), marsupials whose adults weigh as little as 6–8 kg but eat up to 1.5 kg of leaves a day and digest them for as long as several days in their extraordinarily long (1.8–2.5 m) intestines. Even so, this poor nutrition allows them to be on the move only about 1 percent of the time (Leach 2002). Consequently, a fructivorous primate of human size would have to eat 3–5 kg of sweet fruits and a folivorous one more than 10 kg of leaves a day, and even then this bulky plant diet would cover no more than about half of the essential protein requirements (Southgate 1991) and would leave little room for vigorous activity.

Obligatory carnivores subsisting largely on easily digestible protein can dispense with cumbersome metabolic arrangements and devote a great deal of energy to rapid pursuits (felids) or to persistent running (canids). Evolution had clearly shifted human capabilities in that direction. The human gastrointestinal tract is about 40 percent smaller than it would be in a similarly sized primate, and the most obvious explanation is that the reduction resulted from progessively larger inclusion of foodstuffs of higher energy density and easier digestibility. In those environments where nuts and seeds, which also have relatively high protein content, were readily available, preagricultural foragers could obtain adequate diets by remaining overwhelmingly vegetarian. But where the energy-dense seeds were absent (in tundras), scarce, or difficult to reach (in arid grasslands or in high canopies of boreal forests), animal foods supplied large shares of overall food needs.

Another meat-related development of major evolutionary importance was the domestication of many animal species that began about 11,000 years ago with sheep and goats and then progressed to cattle, pigs, horses, and camels (Alvard and Kuznar 2001). These carefully husbanded deferred harvests of high-quality foodstuffs constituted a valuable resource that acted as a buffer against failures of field crops, but their management required a great deal of strategizing, planning, cooperation, and sudden problem-solving, qualities that are uniquely human.

There is obviously no representative pattern of preagricultural diet, but when the average meat intakes of chimpanzees are prorated to more massive humans they indicate expected consumption of about 6–17 kg a year per capita. There would thus seem to be a good evolutionary argument for the annual presence of at least 10–20 kg of meat in average diets in environments where a wide variety of other high-quality foodstuffs were always available. Conversely, the evolutionary evidence makes it clear that there are no adverse health effects in deriving, as did the traditional Inuit, more than 90 percent of all dietary energy and virtually 100 percent of food protein from fat and meat of aquatic mammals in environments lacking a variety of good plant foods and in populations whose active life requires high energy inputs.

Extremes of daily intakes of animal protein among the remaining foraging populations that were studied by modern methods after 1950 confirm the wide range of per capita meat, and hence protein, intakes. Healthy and active adults require daily about 60 g of good-quality protein, but more than 300 g of protein were available to Alaskan Inuit feeding on whales, seals, fish, and caribou, while the foragers in arid African environments, subsisting mainly on nuts and tubers, had at their disposal often less than 20 g of protein per day (Smil 1994).

Meat in traditional agricultural societies

Gradual adoption of sedentary farming, the process that started about 10,000 years ago and took thousands of years to complete, greatly boosted the maximum population density—by as much as four orders of magnitude[10]—but in most instances this gain was paid for by a marked decline in the average quality of nutrition. Lowered intakes of meat almost always meant generally lower availability of complete protein as well as of several vitamins (A, B_{12}, D) and minerals (above all iron). These declines were reflected in diminished statures of sedentary populations (Cohen 2000; Kiple 2000). Quantifying these shifts is another matter. Archeological findings and written documents offer a wealth of information about the composition of diets in antiquity, but the anecdotal and fragmentary nature of this evidence precludes its conversion to any coherent summaries of secular trends. These records do not improve noticeably before the seventeenth century, and even afterward it is impossible to extrapolate detailed information for certain localities or socioeconomic groups to large-scale or national averages.

The only solid generalization in accord with documentary and anthropometric evidence is the absence of any persistent trend in per capita meat consumption. A cautious quantification may be phrased as follows: average per capita meat intakes in traditional agricultural societies were rarely higher than 5–10 kg a year; in most subsistence peasant societies of the Old World, meat was eaten no more frequently than once a week and relatively larger amounts were consumed, as roasts and stews, only during festive occasions. Growing populations and the necessity to convert more pastures into arable land reduced average per capita meat supply in many countries of early modern Europe compared to the relative abundance during the late Middle Ages (Flandrin 1999). Gradual intensification of farming made large domestic animals (cattle, horses, camels) even more important sources of animate energy (both as field draft animals and in local transport and crop processing), dung (traditional farming's principal source of recycled nutrients), and milk, rather than suppliers of meat.

Consequently, animal foods provided generally less than 15 percent of all dietary protein, and saturated animal fats supplied just around 10 percent of all food energy for preindustrial populations. These conclusions are not in conflict with apparently reliable claims of some relatively high meat intakes among ruling elites, in cities in general and among rich urbanites in particular, or among marching armies—but such high consumption rates were restricted to small segments of populations. Low yields of grain and tuber crops limited the availability of high-quality feeds, and the inherent inefficiency of traditional animal feeding resulted in slow weight gains and low productivities (Smil 1994). These realities, prevalent well into the nineteenth century, had greatly constrained the total amount of available meat in traditional agricultural societies, and they are the reason for rejecting such vastly exaggerated claims as the average daily per capita supply of 3 pounds of meat in Berlin in 1397 (that would translate to about 500 kg/year) or averages of between 72 and 100 kg/year in Nuremberg in 1520 (cited by Teuteberg and Flandrin 1999).

Perhaps the best way to illustrate the range of reliably documented intakes is to present a few numbers and a few revealing quotations. Even in the richest European countries meat was a rare treat in ordinary households of the late eighteenth century. Antoine Lavoisier (1791) reported in his brochure on the riches of France that large numbers of peasants ate meat only at Easter and when invited to a wedding. The best available data show that at the beginning of the nineteenth century average meat consumption contributed less than 3 percent of all food energy in France (Toutain 1971). Similarly, an English hired hand told Sir Frederick Morton Eden (1797: 227) that in his household they had

> seldom any butter, but occasionally a little cheese and sometimes meat on Sunday.... Bread, however, is the chief support of the family, but at present they do not have enough, and his children are almost naked and half starved.

A recent quantitative reconstruction of average per capita food intakes by poor English and Welsh rural laborers between 1787 and 1796, based partly on Eden's report, ended up with 8.3 kg/year (Clark, Huberman, and

Lindert 1995). Urban consumption was generally much higher, but even in privileged Rome average per capita supply of meat fell from almost 40 kg during the late sixteenth century to around 30 kg by 1700 (Revel 1979), and in Naples the decline was even steeper, by two-thirds, between 1570 and 1770 (Flandrin 1999). Average German per capita meat consumption was less than 20 kg before 1820 (Abel 1980), and even as late as the 1860s meat consumption of the poorer half of the English population was barely above 10 kg (Fogel 1991). In contrast, a Tudor soldier was provisioned with two pounds of beef or mutton a day, in 1588 the Bury House of Correction had a daily allowance of one-quarter lb of meat or about 40 kg/year, and well-off New Englanders consumed close to 70 kg of meat a year during the mid-eighteenth century (Derven 1984).

Meat remained a rarity among China's subsistence peasants until the last quarter of the twentieth century. Buck's (1930) detailed statistics gathered in several Chinese provinces during the early 1920s show annual meat intakes as low as 1.7 kg/family in today's Hebei (i.e., less than 300 g a year per capita) and as high as just over 30 kg (or about 5 kg/capita) in Jiangsu. His later (1929–33) surveys in 22 provinces of the country indicated average daily consumption of about 80 kcal of meat for adult males, all but 15 percent of it being pork (Buck 1937). This rate translates to about 8 kg of meat (including lard) per working adult male or to less than 3 kg/capita. As in late-eighteenth-century France, many peasants, particularly in China's arid north, ate meat only two or three times a year. Another revealing number is that during the early 1930s meat supplied only about 2 percent of all food energy (not unlike in France of the 1780s), or only about half as much as the (by the Chinese) much-disliked potatoes and less than a third as much as soybeans and beans (cereal grains dominated the supply, with about 83 percent of the total).

Meat eating was even less common in Japan, where various Shinto taboos on the eating of cattle, horses, and fowl (seen as announcers of dawn rather than sources of food) were generally respected until the fifteenth century (Ishige 2000). But even afterward the country's limited pasture and high population density, which required all arable land to be used for food crops, kept average per capita meat consumption at less than 2 kg/year; this very low rate prevailed even during the first century of Japan's post-Tokugawa modernization, as did the virtual absence of dairy products.

India's Buddhist-derived emphasis on *ahimsa* (compassion toward all living things) has made the country culturally the least hospitable territory for human carnivorousness: the average pre-1900 per capita meat consumption of less than 1 kg/year is a very nonrepresentative national mean, as large shares of both the poorest peasantry and the social elites never ate any meat.[11] Food balance sheets show levels below 5 kg/year (carcass weight including offal) until the late 1980s (FAO 2002). Consequently, the only preindustrial societies with relatively high meat intakes outside Europe and North America were pastoral Mongolia (sheep, goats, and cattle), Argentina (beef), and Australia and New Zealand (mutton and beef).

Modern dietary transition and its outcomes

Major dietary change got underway in Europe only during the mid-nineteenth century, and its scope ranged from eliminating any threat of famine to the founding of highly frequented restaurants and the emergence of *grande cuisine*. Increased consumption of meat was among the most important markers of this dietary transition, which was driven by combined forces of improved agricultural productivity, rapid industrialization, and widespread urbanization. The other universal components of that transition have been lower consumption of staple cereals and legumes, rising intakes of dairy and aquatic products and of sugar and fruits, and a wider choice in every food category (Popkin 1993; Poleman and Thomas 1995; Caballero and Popkin 2002).

The onset of these changes varied by more than a century, starting first in Western Europe during the latter half of the nineteenth century, noticeably affecting Mediterranean Europe only after 1900 and East Asia only after 1950. The pace of the worldwide dietary change accelerated after World War II as the increasingly mechanized agriculture began receiving higher energy subsidies (directly for field machinery, indirectly for agricultural chemicals and crop breeding) and converted from traditional, low-yielding varieties to new high-yielding cultivars.[12]

Higher yields made it possible to use a larger share of grain harvests in animal feeding. In 1900 just over 10 percent of the world's grain harvest was fed to animals, most of it going to energize the field work of draft horses, mules, cattle, and water buffaloes rather than to produce meat. By 1950 the global share of cereals used for feeding reached 20 percent, and it surpassed 40 percent during the late 1990s (USDA 2001a). National shares of grain fed to animals now range from just over 60 percent in the United States to less than 5 percent in India. The continuing rise in the global demand for meat means that an even larger share of cereals will be fed to animals. Refrigerated shipments of meat began during the 1870s, and the world meat trade has grown steadily to account for nearly 10 percent of all red meat and poultry production (FAO 2002). Expectedly, the pace of the dietary transition has been highly country-specific as it progressed slowly in parts of Europe but moved rapidly in post–World War II Japan to reach a new equilibrium in less than two generations, and it was even more rapid in China after 1980 (Popkin et al. 1993).

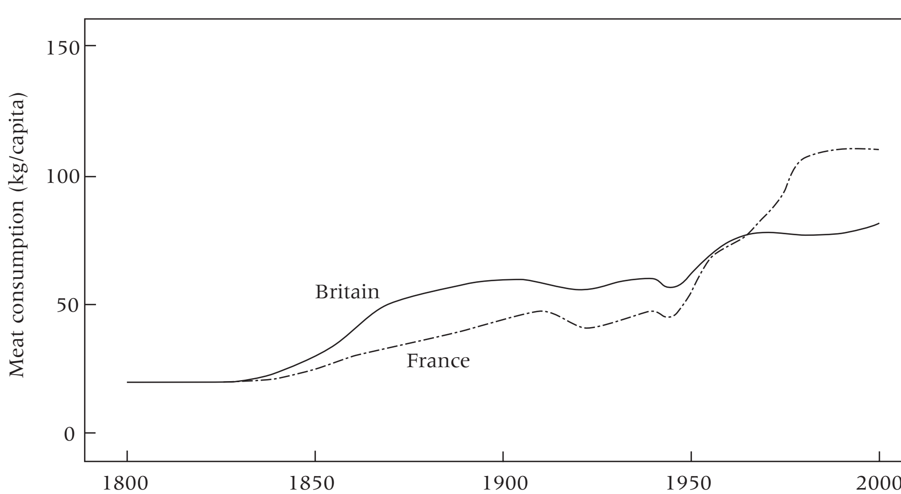
Historical data allow a fairly reliable reconstruction of this progress for the past two centuries in France and Britain (Dupin, Hercberg, and Lagrange

1984; Perren 1985). French meat consumption remained unchanged during the first half of the nineteenth century, and then it took over 80 years to double the average annual rate to more than 50 kg (carcass weight) per capita; the second doubling took only 25 years between 1950 and 1975 (as seen in Figure 1). British per capita consumption rates (also as carcass weight) rose faster during the nineteenth century, roughly tripling to a fairly high level of almost 60 kg by the year 1900. This was followed by stagnation until the late 1940s, and the subsequent growth lifted the average above 70 kg/year by 1970 but not above 80 kg/year by the century's end (Figure 1).

Average US meat consumption (as edible weight) was far ahead of the European means throughout the nineteenth century, and only after 1950 did Europe's richest countries match the level reached by the United States 100 years earlier. A well-documented US record begins in 1909, with about 51 kg of boneless trimmed (edible) weight per capita (excluding edible offals and game) (USDA 2002a). Reversal of the subsequent stagnation and decline (to 40 kg by 1935) began during World War II and the average rate surpassed 70 kg (a typical adult body weight) by 1967 and reached about 82 kg by the end of the 1990s (see Figure 2). Japan's average rate surpassed 3 kg (carcass weight, including nearly a kg of whale meat) only in 1955, but thereafter the country's rapid economic growth propelled it to 12 kg by 1965, 25 kg by 1975, and to about 45 kg by 2000 (FAO 2002).[13]

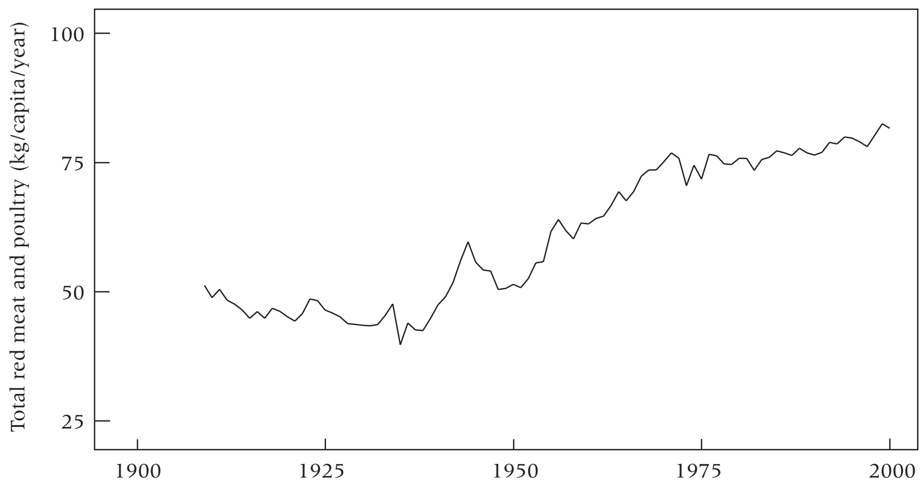
Official Chinese statistics of meat production (in carcass weight) indicate an unprecedented rise from 11.2 kg/capita in 1975 to 25 kg by 1990

FIGURE 1 Meat consumption in France and Britain, 1800–2000



SOURCES: Average per capita rates according to Toutain (1971); Dupin, Hercberg, and Lagrange (1984); Perren (1985); and FAO (2002).

FIGURE 2 Average US per capita consumption of red meat and poultry, 1909–2000



SOURCE: Data for trimmed boneless meat from USDA (2002b).

and to nearly 50 kg by the end of the 1990s (NBS 2000). If true, this would have been the fastest increase of meat eating in history. But the official statistical yearbook (NBS 2000) puts actual per capita purchases of meat during the late 1990s at about 25 kg/capita for urban households (unchanged in a decade) and the meat consumption of rural families at less than 17 kg, up from about 13 kg in 1990, a clear indication that output data for the 1990s became increasingly exaggerated. Unfortunately, FAO balance sheets (FAO 2002) calculate China's average per capita meat supply on the basis of clearly exaggerated production claims, putting it at nearly 49 kg/capita in 1999 (including, as all FAO statistics do, consumption in Taiwan). In addition, unimproved varieties of traditional Chinese pigs produce carcasses that contain more fat than meat.

Higher per capita rates of meat intake have been accompanied by changing patterns of consumption. Some of them have traditionally been highly country-specific, as variable shares of beef, pork, mutton, goat, poultry, and other meats reflected environmental conditions, agricultural and pastoral practices, cultural attitudes, and dietary taboos. One kind of meat was often dominant: Argentinian beef and Chinese pork are perhaps the two best examples. Gradual homogenization of meat consumption and the rising share of poultry in the total supply are two clear markers of dietary modernization. Consumption of meats other than beef, pork, and poultry has been declining throughout the Western world. Mutton, goat, horse, and other meats supplied 15 percent of French consumption in 1960, but less than 10 percent now; the British have halved their mutton eating since

1960. Horsemeat is now a rarity in the West outside France, Benelux, Germany, Italy, and Spain.[14]

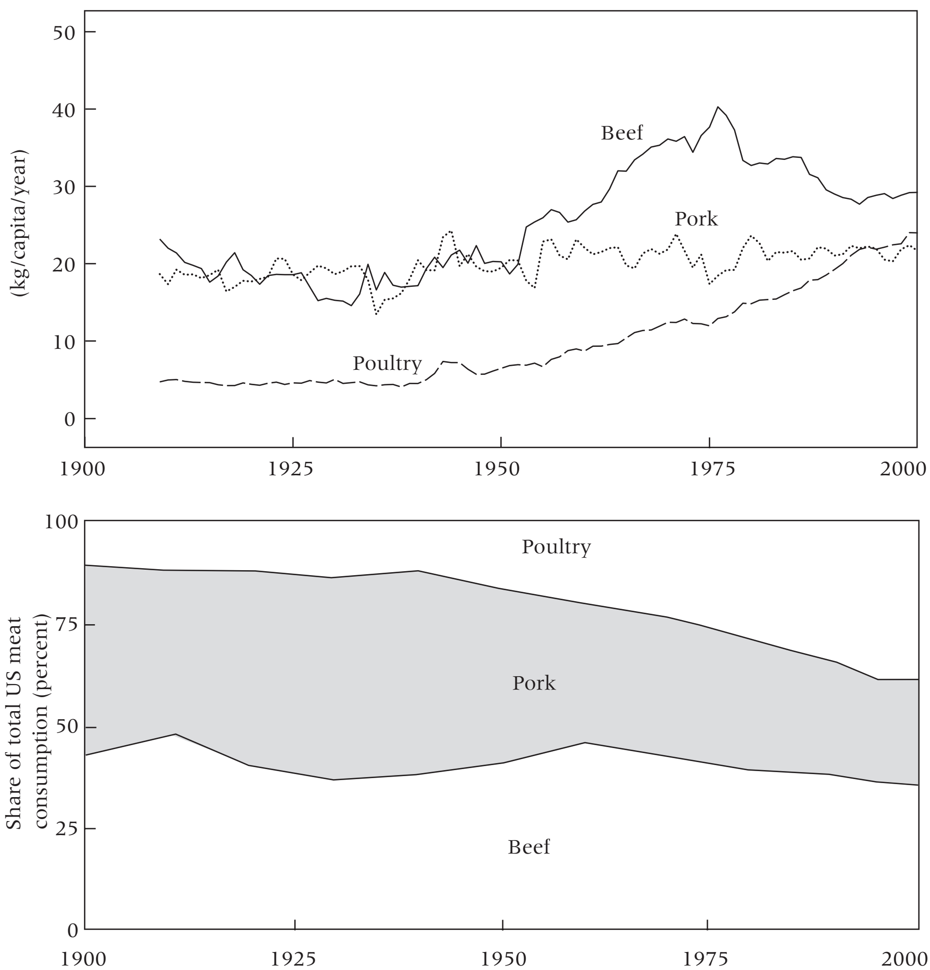
Beef eating was declining nearly everywhere long before the scares about bovine spongiform encephalopathy (BSE), which may cause a variant Creutzfeld–Jakob disease (vCJD) in humans, led to abrupt drops in demand. In the United States, a country unaffected by BSE, beef's share of total meat consumption declined from a high of about 50 percent in 1910 to about 35 percent in 2000 (USDA 2002a; see Figure 3). In Britain, the country hardest hit by vCJD, beef consumption is down a third in absolute terms and 40 percent in relative terms (to just about a fifth of the total demand) when compared to 40 years ago. The decline of beef eating has been less steep in France, from about 37 percent of meat intake in 1960 to 26 percent in 2000 (FAO 2002).

Pork may be retaining or even slightly increasing its absolute per capita consumption rate, but its relative share is down in many countries. In the United States, where the absolute per capita intake of pork remained remarkably constant throughout the twentieth century, its share fell from a high of 50 percent in the early 1930s to 27 percent by the late 1990s (Figure 3), and recently it has slipped even in China as mass-produced broilers have accounted for a fifth of all meat consumption. Poultry's share rose from 10 percent in 1900 to 37 percent by 2000 in the United States (Figure 3); in France it more than doubled to 25 percent since 1960; and the absolute demand more than quadrupled in Britain, where poultry now accounts for 36 percent of the meat total, the highest share among affluent countries.

Finally, some revealing global perspectives. With global annual output of nearly 500 million tonnes (Mt), cow milk is the most important animal food, far ahead of 80 Mt of pig meat (FAO 2002). But because fresh milk (about 87 percent water) has only 3.5 percent protein while moderately fat pig carcass has about 10 percent protein, cow milk now contains only about twice as much protein as the world's rising pork output; and total meat production, including poultry, now exceeds 200 Mt a year and it supplies more protein than do all milks. Poultry now produces more meat (nearly 60 Mt/year) than cattle (beef and veal), and demand for broilers continues to rise on every continent. Consumption of hen eggs is now at more than 40 Mt a year, and recent rapid growth of aquaculture (with combined freshwater and marine output now close to 30 Mt a year, equal to nearly a quarter of ocean catch) has put cultured fish, crustaceans, and mollusks ahead of mutton.

The global average of annual per capita meat supply (determined by the aggregation of national food balance sheets) was about 38 kg (carcass weight) in the year 2000, but in this dichotomous world very few countries actually consume this amount of meat. The mean for affluent countries is now close to 80 kg/year while FAO's mean for modernizing countries is only about 27 kg/year, and the actual figure should be lower because of the

FIGURE 3 Average annual per capita consumption (top panel) of the three major kinds of meat in the United States, 1909–2000, and their relative shares, by weight, in total meat consumption, 1900–2000 (bottom panel)



SOURCE: Data for trimmed boneless meat from USDA (2002b).

inclusion of the exaggerated official Chinese claim of nearly 50 kg/year (FAO 2002). By the last century's end, the population of affluent countries represented only one-fifth of the global total, but these countries produced and consumed two-fifths of all red meat and three-fifths of all poultry.

The current list of top carnivorous countries (using FAO's average per capita supply in terms of carcass weight and including all offal) is headed not only, as might be expected, by the United States and Australia but also by Ireland, Spain, and Cyprus, all with annual availability between 115 and 125 kg (carcass weight). New Zealand, Denmark, France, Canada, and Argentina are not far behind. Meat supplies in these countries are an order of magnitude higher than in such poor populous countries as Indonesia, Pakistan, and Ethiopia. The lowest ranks are, at around 5 kg/year or less, occupied by Bangladesh, India, and a number of countries in sub-Saharan Africa. In contrast, Brazil's average annual per capita meat supply is, at about 80 kg, nearly twice the Russian mean.

In macronutrient terms, meat now supplies 10 percent of all food energy and more than 25 percent of all protein in rich countries, while the corresponding shares are, respectively, merely 6 percent and 13 percent for the poor world. But the relative importance is reversed for lipids associated with meat: in poor countries meat fat provides about 25 percent of all lipids, while the growing demand for lean meat has reduced that share to about 20 percent in the affluent world. Extending significantly higher meat intakes to the world's roughly one billion people with moderate incomes and then also to some 4 billion with low incomes would require a massive expansion of animal husbandry and hence a substantial increase of feed harvests. Better management of pastures, as well as their regrettable but inevitable expansion due to continuing deforestation in parts of Latin America, Africa, and Asia, will meet some of this additional need—but most of the additional feed will have to come from arable land.

As already noted, increasing levels of meat production necessitated a steady rise in the share of cereal and leguminous grains devoted to feeding. Conversion of this plant energy and protein into meat is accompanied by large metabolic losses. As a result, grain harvests in highly carnivorous countries, or in countries producing feeds for export, must be multiples of those needed for direct human consumption, and the food demand of a modern urbanite has to be a multiple of the area claimed by an overwhelmingly (or entirely) vegetarian subsistence peasant. In order to understand the basic agricultural and environmental implications of this shift, we must recognize major metabolic differences among principal domesticated meat animals.

Animal feeding requirements

Feeding grain crops to animals always entails a loss of potential food output: food grains cultivated in place of feed crops would yield more digestible energy, as well as more protein, although meat protein is superior to that harvested in cereals or legumes. Energy and protein losses caused by inherent inefficiencies of animal growth and metabolism vary widely among domesticated species. The most common choice for calculating that inefficiency—in the United States as units of feed, expressed in terms of corn equivalents containing gross energy of 3,670 kcal/kg, needed per unit of live weight gain—misleads in several ways. As already explained, edible parts of meat supply range from less than 30 percent to more than 60 percent of live weight. Consequently, besides the standard ratios I will also express feeding efficiencies in terms of edible meat. I have based my comparative calculations on widely accepted equations and recommendations predicting feed intake of meat-producing animals (NRC 1987, 1988, 1994, 1996).

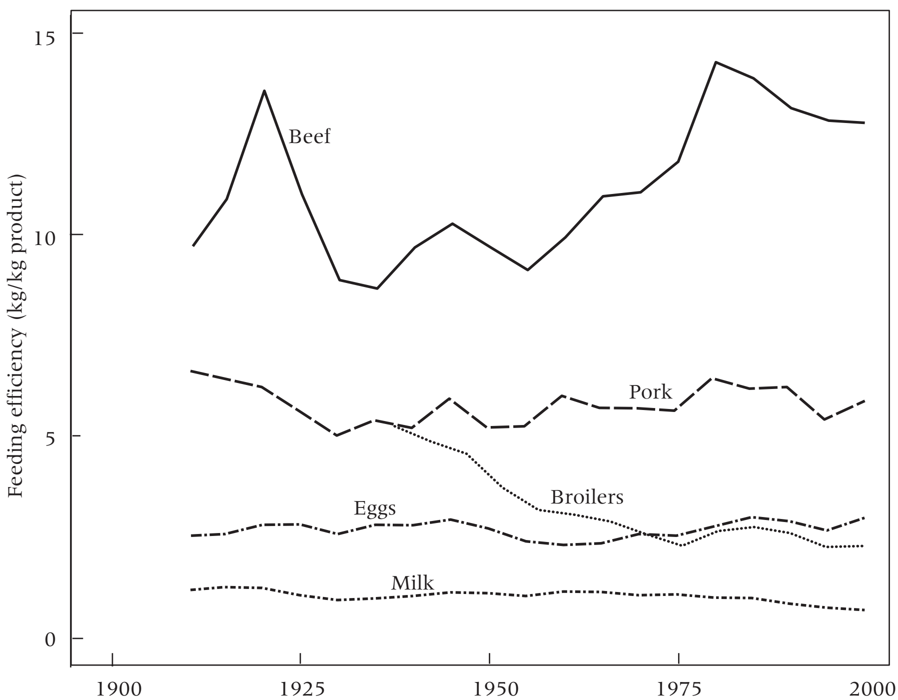
No commercial meat is produced with higher feeding efficiency and at a faster rate than that of chicken. In the United States the average time needed to produce a broiler was cut from 72 days in 1960 to 48 days in 1995, while the bird's average slaughter weight rose from 1.8 to 2.2 kg and the feed/gain rate fell by about 15 percent (Rinehart 1996). When chickens are fed a well-balanced diet (a mixture of corn and soybeans containing about 21 percent protein), cumulative feed/gain ratios are as low as 1.5–1.8 for lighter birds slaughtered after 4–6 weeks, and between 1.8 and 2.0 for birds in the most common range of 2.0–2.5 kg (NRC 1994). The USDA's long-term records on poultry production, available from the mid-1930s when broilers were produced no more efficiently than pigs, show the only instance of a steady improvement of average feeding efficiency among the country's meat animals, indicated in Figure 4 by a decline in the ratio of the feed/gain rate.

Pigs make good meat animals because their basal metabolism is up to 40 percent lower than expected for their body mass, while for cattle it is up to 15 percent higher than expected. As a result, pigs at the midpoint of their growth will convert almost two-thirds of their metabolized energy into weight gain, while the share for a 300-kg steer is only around 45 percent (Miller et al. 1991). Moreover, pigs have a short gestation time (114 days) and a high reproduction rate (litter ranging from 8 to 18), and they grow rapidly, reaching slaughter weights (90 to 100 kg) just 100–160 days after weaning (Pond et al. 1991; Whittemore 1993). The feed/gain rate for North American pigs from weaning to slaughter ranges between 2.5 and 3.5.

The addition of feeding costs of the breeding stock and adjustments for environmental stresses, disease, and premature mortality can significantly raise overall feed/gain rates. The long-term records of pig feeding kept by the US Department of Agriculture since 1910 show a nationwide feed/live weight gain ratio of 6.7 in 1910, and after an initial decline it has fluctuated between 5.0 and 6.5 ever since (USDA 2002b; Figure 4). The main reason why continuous improvements in feeding have not resulted in better gain rates has been the quest for less fatty pigs. Leaner animals are inherently more costly to produce than lardy ones: the efficiency of metabolizable energy conversion to protein in pigs peaks at about 45 percent, while conversion of feed to fat can be as much as 75 percent efficient.

Calculations of overall feed/gain efficiency ratios for beef are complicated by a variety of arrangements under which meat production takes place (Ørskov 1990; Jarrige and Beranger 1992). The two extremes are entirely grass-fed beef that requires no feed concentrates, and calves raised after weaning in a feedlot on a diet of grain combined with feed additives, growth

FIGURE 4 Comparison of feeding efficiencies (kg of corn equivalents/kg of live weight) for US beef, pork, broilers, eggs, and milk, 1909–2000



SOURCE: Based on Figure 3 in Smil (2002b).

promoters, and disease preventers (a minimal share of roughages must be included for normal ruminant digestion). The actual time that North American beef animals spend in feedlots on high-grain diets varies greatly. Calves born in early spring may remain with cows on pasture until November, and then (weighing 200–300 kg/head) they are either moved to a feedlot or maintained on forage for another year and only then (as yearlings weighing 300–400 kg) put on a diet of concentrates. Feedlot animals gain between 1.0 and 1.3 kg a day—growing much faster than grazing animals, whose daily gains average no more than 0.5 kg—and they spend commonly up to 200 days in feedlots before reaching the market weight of around 500 kg.

While cattle are unmatched converters of roughages that can be digested only by ruminants they are relatively poor performers in turning grain feed into meat. Thus, one of the leading experts on, and proponents of, cattle husbandry (Ørskov 1999: 3) concluded that

> feeding grain to ruminants is biological and economic nonsense: it is a misuse of arable resources, a misuse of a ruminant animal's objective potential,

it is polluting, it is dependent on whims of economic policy and it is driven by commercial gain, not human need.

As already noted, cattle's basal metabolism is higher than expected, and their large body mass and long gestation and lactation mean that the feed requirements of breeding females in cattle herds claim at least 50 percent more energy than required for pigs. For growing and finishing steer and heifers (calves and yearlings), North American and European feed/live weight gain ratios range between 6 and 9. Adjusting these rates for the costs of reproduction and growth and maintenance of sire and dam animals raises the feed/gain ratio of herds to over 10, and the USDA's feed/gain data for all of the country's cattle and calves show a pattern fluctuating between 9 and 14 kg of corn equivalents per kg of live weight gain (see Figure 4). But because nearly all beef animals in North America spend only a part of their lives on a grain diet (they enter feedlots only after they reach 45–60 percent of their final weight), this total should be adjusted downward for a more meaningful comparison with nonruminant animals whose diet does not include forages.[15]

Using the typical USDA rates for entire animal populations and expressing the feeding efficiencies in units of concentrate feed per unit of edible weight only accentuates the differences among major kinds of meat produced from cereal and leguminous grains (see Table 2). Broilers are by far the most efficient producers, pigs require roughly twice as much feed per unit of edible meat, and feedlot-fed beef needs five times as much grain per kg of meat as chickens. Chickens are also the best converters of plant-to-animal protein (about 20 percent efficiency), beef cattle again the worst.

Typical efficiencies of protein production via animal feeding are thus very wasteful: at least 80 percent and as much as 96 percent of all protein in cereal and leguminous grains fed to animals are not converted to edible protein. Metabolic imperatives dictate that any meat production exploiting mammalian or avian species must be a less efficient way of securing

TABLE 2 Feed conversion efficiencies of major animal foods

	Milk	Carp	Eggs	Chicken	Pork	Beef
Feed conversion (kg of feed/kg of live weight)	0.7	1.5	3.8	2.5	5.0	10.0
Feed conversion (kg of feed/kg of edible weight)	0.7	2.3	4.2	4.5	9.4	25.0
Protein content (% of edible weight)	3.5	18	13	20	14	15
Protein conversion efficiency (%)	40	30	30	20	10	4

SOURCE: Based on Table 5.1 in Smil (2000).

high-quality and easily digestible animal protein than is provided in milk and eggs. Consequently, if the delivery of superior protein were the only objective of animal husbandry, then all high-quality feed should be reserved for dairy cows and laying hens; and the only meat-producing animals that would not compete for arable land with humans would be ruminants, animals that are uniquely adept at converting feed that no other domesticated species can use, raised on grasslands that are not potentially suitable for conversion to crop fields. But people choose to eat specific foodstuffs, not generic nutrients, and their preference for meat causes many environmental disruptions.

Environmental consequences of meat production

First a few revealing quantitative approximations regarding the surprising but curiously little-noted biomass of domestic animals. The rapidly growing zoomass of domestic animals has made dairy and meat mammals the dominant class of vertebrates on Earth. In 1900 there were some 1.3 billion large animals, including about 500 million head of cattle; a century later, after growing at about the same rate as humans, the count of large domestic animals surpassed 4.3 billion, including 1.65 billion head of cattle and water buffaloes and 900 million pigs (FAO 2002). My calculations based on the best available head counts and on typical average body weights result in less than 180 Mt of live weight of domesticated zoomass in 1900, and in no less than 620 Mt in 2000, a nearly 3.5-fold increase during the twentieth century (Smil 2002a); in contrast, the zoomass of wild terrestrial mammals is now most likely below 40 Mt, or less than 10 percent of the biomass of domesticated meat and dairy species (Smil 2002a).

The contrast is even greater for the largest herbivores. Bovine biomass is now almost 450 Mt, while the zoomass of remaining African elephants, whose population was about 387,000 in 1995 (IUCN 2001), is, even when using a high average body mass of 2,500 kg/elephant, less than 1 Mt, or not even 0.2 percent of the worldwide mass of cows, bulls, calves, steers, and heifers. Moreover, the global cattle count has grown by some 130 million head since 1980, while African elephants, although prospering in some countries, now number only a fraction of their total a half-century ago. This is not an appealing thought: if sapient extraterrestrial visitors could get an instant census of mammalian biomass on the Earth in order to judge the importance of organisms simply by their abundance, they would conclude that life on the third solar planet is dominated by cattle.

As with so many other realities, environmental consequences of animal husbandry are different in rich and poor countries. Expansion of livestock production in the poor world brings further degradation of natural ecosystems and loss of biodiversity arising from deforestation (although the expansion of pastures is not, as is sometimes claimed, the primary reason for the loss of forest cover in most tropical countries) and regular grassland burning (Nicholson et al. 2001). Overgrazing, trampling, and excessive soil erosion are common environmental degradations on improperly managed pastures.[16] In contrast, the rich world's carnivorousness, based on high-quality concentrates, requires large areas of feed crops. Its most obvious environmental impacts result from concomitant increases in applications of fertilizers and pesticides and from greater soil erosion under corn and soybeans, the leading row crops. How much additional plant food could be produced if we were not growing all those feed crops for our animals?

A great variety of concentrate feed mixtures, crop yields, and feed shares supplied by byproducts and ruminant roughages means that actual land requirements of animal feeding can range two- or even threefold for the same species. I calculated representative North American means by using a weighted average for typical yields of concentrate feed crops, assuming a common share of 20 percent of the feed coming from byproducts (as well as the minimum 15 percent share of ruminant roughage) and applying these factors to the previously derived typical feeding efficiencies. Chickens and pigs have similar land requirements in terms of overall food energy, but broilers need the least amount of land to produce a unit of protein, less than one-tenth the need of beef cattle (Smil 2000).

But the farmland needed to grow feed for animals is not simply proportional to specific conversion efficiencies. A significant share of feed comes from byproducts generated by processing of food crops, mainly by grain milling and oil extraction. In addition, even when raised in feedlots, ruminants need a minimum share of roughages (straw, hay) whose production does not compete with the growing of food crops. Perhaps a more revealing approach is to compare the overall land claims between largely vegetarian and highly carnivorous societies. An overwhelmingly vegetarian diet produced by modern high-intensity cropping needs no more than 800 m^2 of arable land per capita. A fairly balanced Chinese diet of the late 1990s, containing less than 20 kg of meat, was produced from an average of 1,100 m^2/capita; the typical Western diet now claims up to 4,000 m^2/capita (Smil 2000). Implications of the last rate are clear: today's world's population eating the Western diet whose meat would be produced with feeding efficiencies prevailing during the late 1990s would need about 2.5 billion hectares of agricultural land, that is, 67 percent more than the existing total.

Extension of the affluent world's carnivorousness to the rest of the global population is thus impossible with current crop yields and feeding practices, and only many as yet unavailable bioengineering advances could bring it to the realm of conceivable achievement. Quantification of current impacts of competition between food and feed crops is not simple. The more than 700 Mt of cereals and leguminous grains now consumed annually by the world's animals are equal to roughly one-third of the global harvest of these crops, and they contain enough energy to feed more than 3 billion people—but only if those people were willing to eat a largely vegetarian diet dominated by corn, barley, sorghum, and soybeans, today's leading feed crops. A more realistic approach is to assume that the area now devoted to feed crops would be planted, to the extent possible, in a mixture of preferred food crops dominated by wheat and rice and that only their milling and processing residues would be used for feeding.

These assumptions would lower the estimate of the additional number of people who could be accommodated on predominantly vegetarian diets to about one billion. The actual number of people who would freely choose such a diet would obviously be much lower. Moreover, because nearly 90 percent of arable land that could be converted from feed to food crops is in affluent countries, additional food produced in that way would only add to the already vast food surpluses of the rich world and would not be readily available to some 800 million of the world's undernourished people (FAO 2000) who do not have incomes to buy it. A recent report by a leading agricultural organization goes so far as to conclude that diverting grains from animal production to direct human consumption would result in little increase in total food protein (CAST 1999).

Adequate water supply is now widely seen as one of the key concerns of the twenty-first century. Few economic endeavors are as water-intensive as meat production in general and cattle feeding in particular (Smil 2000). Broilers have by far the lowest direct (drinking) water requirement, no more than one-third of pigs' need per unit of protein, and less than one-tenth the rate needed by cattle. Naturally, as with the land, the indirect water needs for growing feed far surpass the direct requirements because the production of common feed crops needs at least 1,000 times their mass in water.[17] Consequently, one could think about international meat trade, even more so than about the grain trade, as one of the most effective ways to avoid huge water consumption by importing nations with scarce water resources, or to exercise comparative advantage by water-rich producers.

The lower the feeding efficiency, the higher the production of wastes. In relative terms (per kg of live weight), beef cattle are the largest producer of feces and urine among meat animals, followed by poultry and pigs. Animals are also particularly inefficient users of nitrogen: even such good protein converters as young pigs will excrete 70 percent of all ingested nitrogen. Not surprisingly, Bleken and Bakken (1997) calculated average nitrogen retention in animal foods in Norway at just about 20 percent. Annual global production of animal manures (including considerable output by dairy animals) now amounts to more than 2 billion tons of dry matter, and with average nitrogen content of about 5 percent it contains about 100 Mt of nitrogen, more than we apply annually in synthetic fertilizers (Smil 2001). However, less than half of that total is produced in confinement where it would be available for collection and later recycling to fields. The relative nutrient content of fresh wastes is very low, mostly between 0.5 and 1.5 percent nitrogen and 0.1–0.2 percent phosphorus, compared to 46 percent nitrogen in urea and 8–9 percent phosphorus in superphosphate.

Even so, animal manures were a valuable resource in all preindustrial agricultures, and they were regularly applied to fields to renew soil fertility. This recycling kept a substantial share of nutrients excreted by animals circulating within agroecosystems. Modern research confirms that adequate manure applications produce crop and pasture yields indistinguishable from those obtained through the use of inorganic fertilizers (Choudhury et al. 1996). But while traditional farmers often had too little manure to produce the best possible yields, the modern separation of large-scale livestock production from field agriculture makes it impossible to recycle the large volume of wastes produced by thousands of animals concentrated in huge feedlots or sties: for example, four-fifths of all US pigs are now fed on farms selling 1,000 or more animals a year (USDA 2002b).

Moreover, these large feeding units are increasingly concentrated in particular areas: in the United States six Midwestern states produce about two-thirds of the country's pork, and Iowa has about 1.6 pigs for every hectare of farmland (USDA 2002b), a low rate compared to about 3.6 animals/ha in Nordrhein-Westfalen and 21.5 animals/ha in Zuid-Nederland (EU 1995).[18] Obviously, cropland in these regions becomes rapidly saturated with manure. Since fresh wastes are mostly water, the radius of their economic distribution is limited to a few km (Sims and Wolf 1994) and they cannot be exported to distant nutrient-deficit areas. Consequently, it is not the provision of feeds but the disposal of wastes that is now putting limits on the size and density of animal production. Some countries have already legislated the limits on the density of farm animals based on their waste output.

Nitrogen volatilized and leached from animal wastes has become a major source of both local and regional environmental pollution. Volatilization of ammonia is the source of objectionable odors from large-scale operations. After their removal from the atmosphere and subsequent bacterial conversion to nitrates, these emissions also contribute to eutrophication and acidification of terrestrial ecosystems (Matson, Lohse, and Hall 2002). Most of the eutrophication—enrichment of waters with plant nutrients—is caused by leaching of nitrates from fertilizers and animal manures. Intensive fertilization of feed crops is the single most important source of these losses. US corn receives about 40 percent of the country's nitrogen fertilizer, and, to the great surprise of most people who think that leguminous crops secure their own nitrogen through symbiosis with rhizobia, about one-fifth of US soybeans now receive supplementary nitrogen in order to guarantee consistently high yields (Smil 2001; USDA 2001b).

Aquatic eutrophication causes excessive algal growth in streams, lakes, estuaries, and coastal waters. These blooms sometimes contain species producing human toxins. One of the most dangerous is *Pfiesteria piscicida*, an estuarine dinoflagellate that kills fish and can cause temporary loss of memory and gastrointestinal problems in humans. Algal blooms increase water's turbidity, and their eventual decay leads to oxygen deficiency, disruption of entire aquatic ecosystems, and loss of biodiversity (Rabalais 2002). Their effects are now found above all in coastal waters heavily affected by nutrient runoff such as the northern Gulf of Mexico, the Chesapeake Bay, the northwestern shelf of the Black Sea, and Japan's Seto Inland Sea. Terrestrial eutrophication may lead to temporary increases in productivity of forests and grasslands as well as to changes in the composition of dominant species and to a loss of biodiversity as nitrophilic plants thrive.

Meat production is also a significant source of greenhouse gases. Enteric fermentation in bovines is a major source of methane (CH_4), a greenhouse gas whose global warming potential (GWP, over a period of 100 years) is 23 times that of carbon dioxide (CO_2) during the first 20 years of its atmospheric residence (CDIAC 2001). And denitrification of nitrates in synthetic fertilizers and in animal manures releases nitrous oxide (N_2O), a greenhouse gas with a GWP nearly 300 times that of CO_2 (CDIAC 2001). But because meat production requires heavy inputs of agrochemicals and inputs of fuel and electricity for manufacturing and operating field and barn machinery, its most important impact on global warming is, nevertheless, due to CO_2 generated from the combustion of fossil fuels used to make these additional inputs. CO_2 is also released from the burning of tropical forests that are being converted to pastures.

Health implications of meat production and consumption

A discussion of health implications should start with the animals themselves, and the matter of animal welfare should not be dismissed as overwrought outbursts of vegetarian activists. All domesticated species reared for meat are social animals, and their well-developed group organizations are drastically disrupted or altogether eliminated by modern farming methods that force these animals to live either in extreme overcrowding or in complete isolation (Mench and van Tienhoven 1986; Fraser et al. 1990). These unnatural conditions result inevitably in heightened stress and lead to a higher incidence of density-promoted diseases. Excessive crowding is most obvious in poultry production. Broilers reared in groups of many thousands in tightly packed cages can have as little space as 450–500 cm^2 per bird. That is a square with a side as small as 21 cm, providing just enough room to stand. In contrast, free-range birds may have as much as 25 m^2 of grass per bird, or 500 times as much space—but because of their higher metabolism they will consume up to 20 percent more feed than their caged counterparts (Appleby et al. 1992).

Pathological demonstrations of crowding include cannibalistic attacks among poultry and pigs. Other common practices that prompt ethical questions about the treatment of domestic animals range from inflicting pain by castration, branding, dehorning, beak trimming, and inadequate stunning before slaughter (Reynnells and Eastwood 1997). No less disturbing are the stress induced through extreme confinement of calves (Wilson, Stull, and Warner 1997) and deep muscle myopathy (atrophy of the inferior pectoralis muscle caused by an inadequate blood supply to the tissue) and skeletal disorders, particularly in the bones of the pelvic limb, associated with the accelerated growth of muscle that is not commensurate with skeletal development in chicken and turkeys (Mench and Siegel 2000). These abnormalities are further exacerbated by the denial of free movement. Moreover, lack of synchronous growth among body components in broilers can contribute to pulmonary hypertension causing excess accumulation of fluids.

These quotidian inhumanities were recently overshadowed by concerns about epizootics that swept through Western Europe and parts of East Asia. By far the most dangerous is BSE, commonly known as mad cow disease. Its cause is another unfortunate and still widely used practice of modern animal husbandry, namely the feeding of processed animal tissues (meat and bone meal) to herbivorous species: in the case of BSE it was the meal prepared from sheep infected with scrapie, an encephalopathy-related disease, fed to calves (Horn 2001). Between 1980 and 1996 some 750,000 head of cattle infected with BSE were slaughtered for human consumption in Britain, and edible products from these animals could have exposed up to 500,000 people to the risk of vCJD, an aggressively fatal disease.[19] In contrast, foot-and-mouth disease epizootics had taken place in most of the world's countries during the twentieth century, but the British outbreak of this highly transmissible viral infection in 2001 was both serious and spectacular because of the total number of animals involved—8.65 million pigs, sheep, lambs, and cattle were killed—and the gruesome manner of their disposal by burning the carcasses on giant pyres (Keeling et al. 2001; Pighealth.com 2002).

Recent epizootics have not been limited to mammals: H5N1 virus spread avian influenza from chickens to 18 people in Hong Kong in 1997 (six of them died). The episode necessitated the destruction of all of the territory's 1.6 million chickens beginning in December 1997. Because the infections coincided with the onset of the usual influenza season, health experts were concerned that human strains might co-circulate with the avian influenza and create new avian reassortant viruses that could be readily spread person-to-person, a development that would raise fears of a new pandemic

(Snacken et al. 1999). Less widespread and less virulent returns of the virus in 2001 and 2002 led to further preventive killings of chickens (nearly 900,000 in February 2002).

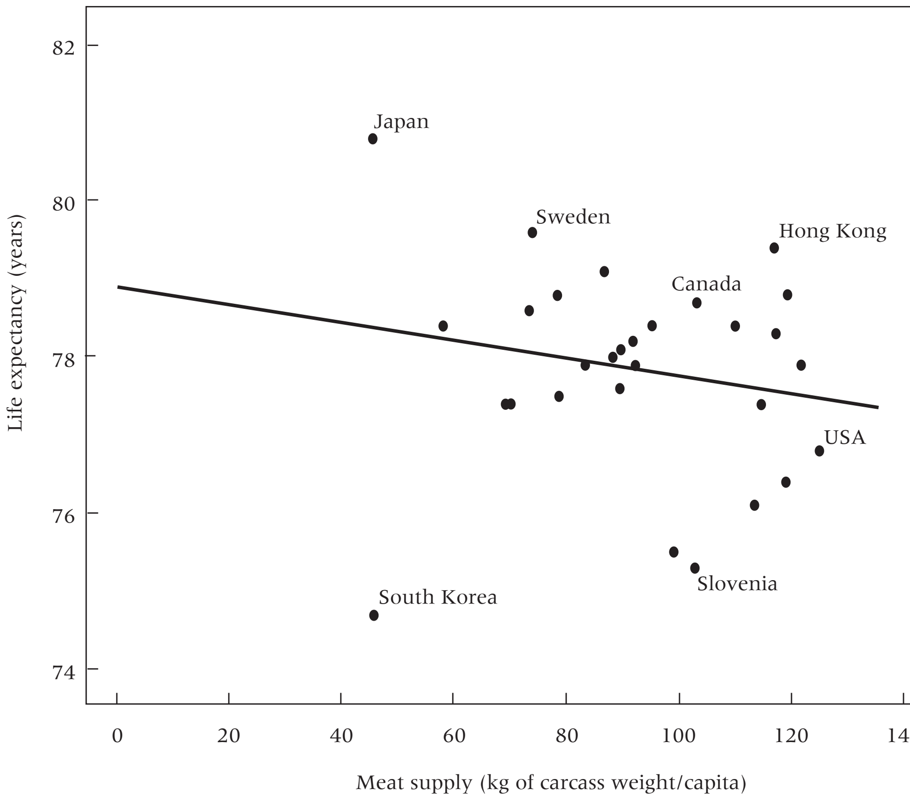
Another health concern has been with us since the beginning of massed animal slaughter in America's sprawling Midwestern abattoirs, memorably portrayed by Upton Sinclair (1906).[20] Few people realize that, nearly a century later, meatpacking remains the country's most dangerous occupation. In the year 2000 some 25 percent of all employees in meatpacking plants, or exactly four times the private-industry average, had a nonfatal occupational injury or a job-related illness (BLS 2002). In addition, serious injuries and illnesses (compared in terms of lost workdays) are nearly five times the national average found in private industry (average incidence of 14.3 percent vs. 3.0 percent in 2000), and the frequency of disorders associated with repeated traumas (mainly back problems and tendinitis) is 30 times higher than the private-industry mean (812 versus 26.3 cases per 10,000 full-time workers in 2000) (BLS 2002). These statistics are less surprising when one realizes that some modern slaughterhouses process as many as 400 cattle per hour and some workers make up to 10,000 repetitive knife cuts every day (Schlosser 2002).

Effects of meat-rich Western diets cannot be seen in separation from other nutritional practices and, indeed, from prevailing lifestyles. The traditional Inuit demonstrated that humans can adapt to a diet consisting of little else but a mixture of meat and animal fat. But particulars of that existence—ranging from a basal metabolic rate higher than in non-Arctic populations to active lives energized by a diet rich in polyunsaturated fatty acids typical of marine mammals (So 1980)—have nothing in common with modern urbanites sheltered from temperature extremes by heating and air conditioning, rarely engaged in prolonged strenuous activity, and consuming both food energy and saturated fatty acids far in excess of actual requirements.

Plotting the average meat supply (carcass weight) in the 30 countries with the highest ranking according to the Human Development Index (UNDP 2002) against the average life expectancy of their populations shows a slightly negative slope (lower life expectancy with higher meat intakes), but the correlation between the two variables is practically insignificant (see Figure 5). On the other hand, there is little doubt that high consumption of animal products in general, and of fatty meat in particular, is responsible, particularly when combined with high intakes of sugar and low levels of everyday activity, for highly obese populations and elevated incidence of several chronic diseases (Hu and Willett 1998). Lakdawalla and Philipson (2002) found that in the United States lower food prices brought by agricultural innovation have been responsible for about 40 percent of the recent rise in weight, while the remainder is due to declining physical activity and other factors.

Prevalence of obesity, defined as having at least a 35 percent excess over ideal body weight, was stable in the United States between 1960 and

FIGURE 5 Absence of correlation between life expectancy at birth and average per capita meat supply (carcass weight) in 30 countries with highest scores on the Human Development Index



SOURCES: Plotted from data in FAO (2002) and UNDP (2002).

1980 at about 25 percent of the adult population and it increased by 8 percentage points during the 1980s (Kuczmarski et al. 1994). By the early 1990s the mean weight gain of 3.6 kg had made every third US adult overweight, with the highest increases among men over age 50 and women between ages 30–39 and 50–59 years (Flegal 1996).

In Canada, where obesity rates are very similar to those in the United States, it is estimated that the total direct cost of obesity accounts for as much as 4.6 percent of the country's health care expenditure for all diseases (Birmingham et al. 1999). A higher incidence of obesity is now also seen in Europe and in such lower-income countries as Mexico, Egypt, and South Africa (Popkin and Doak 1998). Even in China the nationwide proportion of overweight urban adults rose from 9.7 percent in 1982 to 14.9 percent in the early 1990s; Beijing's rate of over 30 percent approaches the North American incidence (Ge 1991; Cui 1995).

Epidemiological studies have linked obesity with generally reduced longevity and specifically with type 2 (non–insulin dependent) diabetes, hyperglycemia, hypercholesterolemia, hypertension, and coronary heart disease (CHD), stroke, and certain malignancies (colon, rectum, prostate, breast, ovary). Obesity's most common structural impacts are orthopedic impairment, pulmonary difficulties, and surgical risk (Belfiore et al. 1991; Cassell and Gleaves 2000). Among nonsmokers up to 90 percent of type 2 diabetes, between a quarter and a third of CHD and cancers, and nearly a quarter of total premature mortality can be attributed to obesity. For the United States it is estimated that CHD incidence could be cut by 25 percent and congestive heart failure and brain infarction by 35 percent if the country's entire population were at optimal body weight (Bray and Gray 1988).

In spite of a growing demand for low-fat cuts of meat, most of the iconic meaty meals consumed by millions of Americans every day are very fatty, either naturally or because of fat added during the cooking process. Burger King's Whopper has 55 percent of its 640 kcal of food energy in saturated fat, and fat shares are 54 percent for McDonald's Chicken McNuggets, 53 percent for Sausage McMuffin, 50 percent for Big Mac (560 kcal), and 47 percent for KFC's Tender Roast Thigh as well as for Pizza Hut's Meatlover's Pizza.[21] Increasingly popular Mexican fast food, particularly beef (or even more so beef-and-cheese) enchiladas and chimichangas, also contains 40–50 percent fat. Compare all of that with less than 5 percent fat in wild meat, less than 20 percent food energy as fat in traditional diets, and with no more than 30 percent of food energy as fat recommended by the American Heart Association (1998).

There has been some moderation of fat intake, with the overall share of lipids in the average American diet declining from the peak of about 42 percent during the mid-1980s to about 37 percent during the late 1990s; but the total amount of saturated fats available in the average US per capita food supply fell by less than 10 percent from the high of 54 g/day to 50 g (USDA 2002b). Two circumstances explain the extraordinarily high fattiness of popular US meals: beef's high lipid content and the preference for deep-fried foods. While modern breeding has produced some very lean pigs, beef animals remain much more fatty.[22] As a result, prime-grade, boneless cuts of pork have between 25 and 35 percent less fat than similar cuts of beef.

Carcasses of US feedlot-fed beef contain about 57 percent water, 24 percent fat, and 18 percent protein (USDA 1999), which means that lipids account for 75 percent of the edible portion, and even what the industry calls "lean trim product" has 50 percent fat. This fact leads to a peculiar situation in which the country that is the world's largest beef producer (and exporter) has become also the world's largest beef importer, purchasing recently nearly one Mt/year of lean trim in order to mix it with its 50 percent-fat trim and lower the share of fat in ground beef, the product whose sales now represent nearly half of the country's beef production and whose appeal is enhanced by making it leaner (Ishmael 1998; NCBA 2000).

Mass addiction to deep-fried foods changes even the leanest meat into a concentrated package of fat. Raw chicken breast is converted from an extremely lean foodstuff with only 110 kcal per 100 g and less than 3 percent fat to McNuggets of 314 kcal per 100 g with 54 percent of food energy in fat. The increasing popularity of processed meat is another source of concentrated fat. The annual US consumption of all types of sausages now surpasses 11 kg/capita, of which nearly 500 g are pepperoni used on pizza (Pizzaware 2001). These processed meats commonly contain 40–50 percent of their food energy in fat.

Cholesterol, a major well-known risk factor in the etiology of coronary heart disease, is an integral part of the cell membrane of animal tissues, hence its presence in meat does not correlate with the fat content of the muscle. Fatty pork and beef have about 70 mg of cholesterol per 100 g, extremely lean white-tailed deer and pronghorn antelope about 110 mg, and even chicken and turkey have about 60 mg (Anger and Brown 1990). This means that frequent consumption of any kind of meat, and particularly so when such organ meats as heart (275 mg/100 g) or liver (450 mg/100 g) are also eaten frequently, is associated with higher intakes of cholesterol. Classic studies of the dietary cholesterol–CHD link (Dawber 1980; Keys 1980) have been recently augmented by a unique set of 100 years of dietary data from Norway (Johansson et al. 1996). They show that a doubling of fat's contribution to total food energy (from just 20 percent in 1890 to 40 percent in 1975) was paralleled by an increase in serum cholesterol corresponding to a 60 percent rise in risk for coronary heart disease (Johansson et al. 1996). A subsequent fall in fat's contribution to 34 percent of all food energy by 1992 resulted in a 30 percent reduction in CHD.

A health impact of an entirely different kind arises from the massive use of antibiotics in all forms of animal husbandry. The Union of Concerned Scientists estimates that more than 11,000 t of antibiotics, eight times as much as used in treating humans, are now fed every year to US domestic animals for nontherapeutic reasons in order to prevent outbreaks of infectious diseases in crowded conditions (UCS 2001). Pigs and poultry each receive about 40 percent of the total and cattle get the rest. What is most worrisome about these practices is that several antimicrobials that are important as human medicines, including tetracycline, penicillin, and erythromycin, are used extensively for these prophylactic treatments. These massive dispensations promote bacterial resistance to essential antibiotics.

The most widely debated recent example is food poisoning (gastroenteritis) caused by the bacterium *Campylobacter jejuni* that acquired resistance to fluoroquinolones (ciprofloxacin and related compounds) when these were used to treat chickens for bacterial infections (FDA 2001). Every year an estimated 8,000–10,000 people in the United States contract fluoroquinone-resistant *Campylobacter* by eating chicken. The spread of vancomycin-resistant enterococci in humans is a development of particular concern among hospitalized patients (Ferber 2002). Thus it has been argued that we should not wait for incontrovertible evidence of harm before acting to preserve the usefulness of many antibiotics in human medicine (Lipsitch, Singer, and Levin 2002).

Finally, a relatively widespread acute medical problem is caused by enterovirulent *Escherichia coli* serotype O157:H7 that causes gastroenteritis and, particularly in children under age five years and in the elderly, a hemolytic uremic syndrome that destroys red blood cells and can lead to kidney failure. Most of this illness, estimated to reach 73,000 cases of infection and about 60 deaths in the United States every year, has been associated with eating undercooked, contaminated ground beef (FDA 2001; CDC 2002). Meat usually becomes contaminated during slaughter by bacteria living in cattle intestines, and the pathogens can then be thoroughly mixed into beef as it is ground. Given the widespread distribution of ground beef from large production facilities, infections from a single batch of contaminated meat can occur in many locations simultaneously.

Possible adjustments

During the last four decades of the twentieth century, global meat production increased more than threefold. The increment between 1980 and 2000 was about 70 percent; the output rose by about 32 percent during the 1980s and by 30 percent during the 1990s, and the annual total surpassed 230 Mt a year by the year 2000 (FAO 2002). Continuation of this trend would see the global meat output at about 300 Mt by 2020, but a plausible argument can be made for a lower increase. There will obviously be major differences between rich and poor countries. Meat is now the single largest source of animal protein in all affluent countries (Japan, with its extraordinarily high fish intake, is the only exception) and this is not going to change in any radical way. Moreover, several circumstances will promote higher meat consumption: more single-person households, high rates of female employment, and reduced willingness to cook are the ongoing shifts that have brought a continuing rise in the consumption of fast, ready-to-serve or easy-to-prepare foods whose key ingredient is often fatty meat (Smil 2000).

While fatty fast food is here to stay (albeit to get a bit leaner with time), there is little chance for any widespread adoption of vegetarianism in affluent societies. Interest in reduced intake of animal foods has grown, and various forms of quasi-vegetarianism (ranging from lactovegetarians who enjoy their yogurt and cheese to lacto-ovo-pisci-vegetarians who eat everything except the red meat) may be practiced by 3–7 percent of Western populations. But the best available US poll showed that vegans, people who never eat any animal foodstuffs, numbered only about half a million (less than 0.2 percent) of the population in 1994 (Stahler 1994).

Similarly, reduction of high Western meat intakes due to higher costs of beef, pork, and chicken is not very likely in a world where commodity prices have experienced a long secular decline. But even suddenly rising prices would make little difference in societies where disposable incomes are now generally so high that demand for such desirable items as meat or gasoline is highly price-inelastic. Converting people to healthy nutrition through education is a Sisyphean task in a society where gluttony-promoting advertisements and Brobdingnagian restaurant servings are a norm, and where a ubiquitous lack of dietary discipline has led to a growing perception of obese people as victims. Still, there are clear signs that the West's high meat intakes are near, or above, the saturation level: average supply grew only marginally during the 1990s in the United States and Britain, remained nearly the same in France and Finland, and actually declined in Germany and Canada (FAO 2002). Future absolute growth of Western meat demand may then largely reflect a slow population increase.

In contrast, relatively low levels of average meat consumption throughout Asia and Africa, generally only moderate intakes in Latin America, continuing dietary transition driven by higher disposable incomes, and the globalization of food distribution translate into potentially high growth of global demand. But this does not mean that today's modernizing countries are set to emulate the dietary pattern of the carnivorous West. The experience of the past two generations shows that although the per capita consumption of meat in most countries of Asia, the Middle East, and Africa has grown appreciably in relative terms, in absolute terms it has remained restrained even as incomes have risen substantially. Consequently, average annual per capita meat supply (in carcass weight) remains below 30 kg in Vietnam and the Philippines, below 25 kg in Turkey and Egypt, below 15 in Pakistan, below 10 in Indonesia and Nigeria, and below 5 in India, Bangladesh, and the poorest countries of Africa (FAO 2002).[23]

Despite the indisputable globalization of tastes, national and regional food preferences still matter around the world, and food taboos, now only weakly held in the West, remain strong among nearly 2 billion Muslims and Hindus. Their mass conversion to, respectively, pork and beef eating is not likely, and the common assumption of high income elasticity of demand for meat may not be realized. A few countries in East Asia have seen a stronger growth, with Taiwan's per capita meat supply now at more than 70 kg/year and South Korea's rate approaching 50 kg. But, as already noted, China's rate has stabilized during the 1990s, as did Japan's intake. Moreover, land constraints alone mean that neither China nor India will be able to replicate the Western levels of feed production, and economic constraints will prevent those countries from being such large importers of animal feed as Taiwan and Japan are. Still, increased demand for imported feed grains could eventually lead to appreciable price increases (and hence to less affordable imports by countries depending on foreign food grain)—or it could stimulate the development of considerable grain-production potential in Ukraine and Russia. In addition, high-quality feed can be used much more efficiently to produce complete protein in milk and eggs, as well as in herbivorous fish. Not surprisingly, Asian aquaculture, particularly in China, has seen a rapid expansion (Smil 2000). As a result, the global growth of meat demand during the next generation may not be relatively as fast as it has been since 1980. Whatever the actual future demand, it is clear what course should be followed in order to moderate various undesirable consequences of globally rising meat consumption. By far the most important strategy for making diets with a reasonable share of meat available to an additional 2–3 billion people during the coming two generations would be to combine maximized feeding efficiencies with moderated intakes in affluent countries, and with appropriate adjustments of specific meat shares.

Fortunately, there are many effective ways to increase the overall efficiency of meat production, including more efficient cropping and the use of supplementary amino acids in order to raise feed conversion efficiencies (OTA 1992; Smil 2000). Further ahead is a partial replacement of meat by novel plant proteins. I have calculated that a relatively modest addition of such proteins to ground and processed meat, whose recent global consumption has totaled roughly 40 Mt, or nearly 20 percent of global meat supply, could result in savings of about 70 Mt of concentrated grain feed, an equivalent of about 10 percent of recent annual global consumption of concentrated feeds (Smil 2002b). More distant still is a large-scale deployment of various bioengineering advances designed to increase the metabolic efficiency of domestic animals and to reduce the volume of their wastes.[24]

Moderation of high Western meat intakes has no known downsides as there are no scientifically demonstrable advantages to the prevailing intakes. For more than a generation the Mediterranean diet has been seen as the most appropriate alternative (Keys and Keys 1975). At the same time, modern Mediterranean diets have been shifting rapidly toward the less desirable pattern of higher meat and fat consumption (Nestle 1995; Zizza 1997). As a result, Spain's meat consumption is now nearly 50 percent higher than the British mean, and Italians consume more meat than do the Germans (FAO 2002). Moreover, as Trichopoulou et al. (1995) argue, the traditional Mediterranean diet works only as a whole, and adjustment of a single factor in an alternative diet (e.g., reducing the amount of meat) may be relatively ineffective. But there has been a clear correlation between Europe's aging populations and reformed diets: a further increase in the share of older, nutrition-conscious cohorts everywhere in Europe will undoubtedly help the shift toward more rational diets.

Advances in our understanding have made many matters clear. There is no scientifically defensible reason for strict vegetarianism. Ours is an omnivorous species, and meat eating is a part of our evolutionary heritage. Even the fundamental and undeniably correct food-chain argument in favor of plant foods has important practical exceptions. Eating closer to the Sun will always support a larger number of people as the interposition of another link in the food chain has to be paid for by inherently large metabolic losses associated with animal reproduction, growth, maintenance, and activity—but this conclusion clearly does not apply to phytomass that cannot be directly consumed by humans. Feeding cattle corn and soybeans produced by intensive cropping is the most irrational meat-producing strategy, but feeding ruminants on appropriately managed pastures and on cellulosic crop- and food-processing wastes is a perfect meat-producing strategy.

Conversely, there is no scientifically defensible reason for the extraordinarily meaty diets now prevailing in most Western countries. These diets do not make people healthier and do not prolong their lives. Instead, to recapitulate, they have undesirable environmental impacts as they generate more soil erosion and lead to higher nutrient losses (above all, of reactive nitrogen) to the atmosphere and to ground and surface waters; to more preventively injected antibiotics that will increase bacterial resistance; to higher emissions of greenhouse gases; and to concentrations of animals in giant feeding enterprises where excessive crowding leads to abnormal behavior and increases the opportunities for devastating epizootics. These diets also contribute to an alarming incidence of obesity and to higher rates of several diseases of highly industrialized populations.

The challenge for low-income countries is not to increase specifically red meat and poultry production but rather to raise the consumption of animal foodstuffs in general so that various combinations of meat, dairy products, eggs, and aquacultured fish assure a better quality of nutrition with fewer negative consequences than have been experienced in the West. Adjustments of relative animal food intakes produced by grain feeding are a highly effective way of reducing the environmental impact of carnivorousness. The most desirable meat shift (from beef to poultry) is made so much easier by the virtually global acceptance of chicken, the most efficient converter of feed to meat; and there are enormous opportunities for increasing the productivity of dairy animals, the most efficient converters of feed to protein, in nearly all low-income countries.

Given their high consumption levels, the affluent countries can do much more to reduce the negative impacts of carnivorousness simply by gradually lowering their average annual meat intakes and by reforming their animal husbandry. A rational society would aim to reduce its average annual meat intake to less than 50 kg/capita, to minimize grain feeding to cattle, to treat all domestic animals in more humane ways, and to resist further concentration of meat production with all of its attendant ills. Success in this combined endeavor would help to moderate the claims the world's animal husbandry makes on land and water, and it would reduce environmental impacts of modern carnivorousness while improving nutrition and health everywhere.

Notes

1 For detailed descriptions and analyses of the strategy, frequency, and success of monkey hunting by chimpanzees, see Stanford (1996, 1998, and 1999). For a comparison of chimpanzee cultures see Whiten et al. (1999).

2 The International Vegetarian Union (2002) maintains a website that offers good summaries and relevant quotations regarding the relationships between vegetarianism and the world's major religions.

3 By far the most popular of recent high-protein, low-carbohydrate diets is the one devised by Robert C. Atkins. It allows an almost unlimited consumption of all animal foodstuffs, and the diet's website—http://atkinscenter.com—carries the impossibly efficacious claims of stunning, and lasting, weight losses.

4 Anecdotal evidence aside, the best recent scientific study is a report by Fraser and Shavlik (2001), which shows that white, non-Hispanic Seventh-day Adventists live longer (by 7.28 years for men, 4.42 years for women) than do other white Californians. In the studied group of 34,192 people, 29 percent were vegetarians.

5 Striated skeletal muscles (voluntarily contracting) account for most of the boneless, dry-matter biomass. Smooth (involuntarily contracting) muscles of internal organs and cardiac muscle are also eaten. Fresh muscles are between 65 and 75 percent water. All proteins, whether of animal or plant origin, contain all essential amino acids that cannot be synthesized by humans, but only animal proteins (meat, milk, and eggs) have all of these amino acids in correct proportions; plant proteins are always deficient in one or more essential amino acids (Smil 2002c).

6 The following are two examples of how these differences translate into average annual consumption rates. FAO's (2002) carcass-based food balance sheets credit the United States and Japan with, respectively, 124 kg and 42 kg of meat supply per capita in 1999. In contrast the USDA (2002a) put that year's trimmed, boneless meat consumption at 82.5 kg/capita, and Japan's Statistics Bureau (2002) lists 77.5 g of meat consumed per day or 28.3 kg/year. In both cases the difference between carcass weight and edible weight is 33 percent.

7 However, fatty foods did not rank exceptionally high on a satiety index that used white bread as the baseline of 100 percent (Holt et al. 1995). Beef was rated at an average of 176 percent, far above yogurt (88 percent) and French fries (116 percent) but not much higher than grapes (162 percent) and below apples (197 percent) and oranges (202 percent). But the outcome of the study was to a large extent forced by its design. The index was constructed by feeding isocaloric portions of 38 different foods: a portion of plain potatoes weighed up to four times more than the other food for the same energy content, and the spuds topped the index with 323 percent.

8 Here is a short list of energy values (in kcal/100 g) and fat content (in g/100 g) for meats of some common domestic and wild animals. Wild animals: buffalo 146, 3.2; Canada goose 171, 3.9; caribou (reindeer) 127, 3.8; cottontail rabbit 144, 2.4; mallard 154, 2.0; pronghorn antelope 114, 1.0; white-tailed deer 143, 1.4; pheasant 149, 0.6; wild turkey 158, 1.1. Domestic animals: pork (total edible, US medium-fat carcass) 513, 52; pork (separable lean) 171, 10.5; beef (total edible, US prime grade) 428, 41; beef (T-bone steak separable lean), 164, 8.1; chicken 107, 2.7. Data for wild animals from Anger and Brown (1990) and Eaton, Eaton, and Konner (1997); data for domestic animals from Watt and Merrill (1963) and USDA (1999).

9 Details on the unique metabolism and nutrition of ruminants can be found in Church (1988) and Onodera et al. (1997).

10 Foraging societies could not support more than a few people per 100 hectares of

territory used for gathering and hunting, while even the earliest traditional agricultures could sustain at least one person/ha of arable land and the most productive ones fared eventually much better: by the end of the nineteenth century China's nationwide mean exceeded 5 people/ha, and double cropping of rice and wheat in the most fertile areas of the country could yield enough to feed 12–15 people/ha (Smil 1994).

11 *Ahimsa* was defined by Vyasa in his commentary on *Yoga Sutras* as "the absence of injuriousness (*anabhidroha*) toward all living things (*sarvabhuta*) in all respects (*sarvatha*) and for all times (*sarvada*)." Even the intent to injure is a violation of *ahimsa*. M. K. Gandhi, the doctrine's most famous modern proponent, was an ardent vegetarian. For more on nonviolence to animals in Asian traditions see Chapple (1993).

12 Between 1900 and 2000 the world's cultivated area expanded by about one-third but the global crop harvest rose nearly sixfold. This occurred because of a more than fourfold increase of average crop yields made possible by a more than 80-fold increase of energy inputs to food production—directly as fuel for machinery and indirectly as energies to produce it, to synthesize agricultural chemicals, and to support the requisite research (Smil 2000).

13 But Japan is unique among affluent countries because aquatic products, rather than the meat of terrestrial mammals and birds, are the principal source of the country's animal protein. Japan's Statistics Bureau (2002) reports that in 1998 (the latest available year) per capita consumption of all kinds of meat was 28.3 kg/year compared to 35 kg of fish and shellfish.

14 Besides the hippophagous part of Europe, horse meat is also consumed in considerable quantities, as it has been for millennia, in Mongolia, and it is popular in Japan (imported from Canada and Australia) where it is either prepared as *teriyaki* or eaten raw thinly sliced as *sashimi*. For more on horsemeat see Gade (2000).

15 Here are two examples of the total amount of concentrate feed consumed by different beef animals (CAST 1999; Goodrich and Stricklin 2000). A 540-kg beef cow marketed at seven years of age is never placed in a feedlot and consumes only forages for most of her life; her only concentrate feed supplements (totaling about 380 kg) are given during winter months to compensate for the low quality of forage feeds. With edible weight being 35 percent of live weight for cows, a beef cow needs just 2 kg of concentrate feed to produce 1 kg of boneless beef, a better rate than for a broiler. A 225-kg calf fed to 500 kg needs 6 kg of high-quality feed per kg of gain during the 250 days it spends in a feedlot. With edible weight being 40 percent of live weight for beef cattle, the calf needs about 7.5 kg of concentrate to produce 1 kg of boneless beef. Of course, this rate refers just to the marginal kg of beef gained during the feedlot phase, not to feed requirements of the entire breeding herd.

16 Two examples of many publications that are highly critical of cattle husbandry in the poor world ("the scourge of cows") are Parsons (1988) and Goodland (1997).

17 The choice of different assumptions results in vastly different totals of water needed to produce the feed for meat production. For example, Pimentel (2001) claims about 100,000 liters (L) per kg of beef, while some beef industry figures are lower than 4,000 L/kg. Assuming that a kg of feedlot-fed beef (actual edible portion) requires at least 20 kg of corn and soybeans to produce and that the cultivation of these crops will evapotranspire no less than 1,000 L/kg of grain, the indirect water need would be about 20,000 L/kg.

18 With very similar average body weights of pigs and humans (about 60 kg/head) the density of pigs in the southern part of the Netherlands translates to nearly 1.3 t of biomass/ha compared to about 230 kg of anthropomass/ha. The addition of nearly 3 head of cattle/ha (averaging about 500 kg) raises the total zoomass to about 2.75 t/ha, or about 12 times the average Dutch anthropomass per hectare of land. The zoomass of domestic animals in the southern part of Holland is thus greater than even the combined biomass of earthworms and other soil invertebrates, and it is surpassed only by the aggregate bacterial mass. For typical biomass rates, see Smil (2002a).

19 Perhaps the worst aspect of the exposure to vCJD is that no one knows how many more people, in addition to nearly 100 who have already died, have contracted the disease:

the eventual total may be just a few hundred but the possibility of an epidemic killing many thousands of people cannot be excluded (Thompson 2001).

20 Particulars have changed but the basic tenor of Sinclair's (1906: 41) description of a pig's journey through the slaughterhouse has not.

21 Of the many listings of the nutritional composition of common American fast-food meals, perhaps the most convenient was compiled by the Minnesota Attorney General's Office (2001): its website—http://www.ag.state.mn.us/consumer/health/fff.asp—allows a user to specify any particular item sold by the major fast-food chains.

22 US breeders reduced the average lard weight from about 14 percent of the pig carcass in 1960 to less than 5 percent by 1983, and total fat was reduced from 30 percent of carcass in the early 1960s to less than 15 percent by the early 1990s, with the subcutaneous layer of fat declining by 0.5 mm a year to as little as 12 mm in mature animals (Pond et al. 1991; Whittemore 1993).

23 All of FAO's food balance sheet totals for meat consumed throughout sub-Saharan Africa underestimate actual intakes because they exclude the consumption of bushmeat—meat obtained from the hunting of wild animals—whose contribution to local diets may be substantial (Njiforti 1996).

24 In fact, less wasteful experimental transgenic pigs are already here. Between 60 and 70 percent of phosphorus (P) in most cereal and leguminous grains are organically bound in phytic acid and hence almost indigestible for monogastric (nonruminant) mammals who lack the requisite enzyme (phytase) to free the phosphate from the molecule (Jongbloed and Henkens 1996). This necessitates the addition of inorganic P to animal diets and results in large losses of excreted P. Transgenic pigs able to produce phytase in their saliva will void manure with phosphorus content reduced by up to 75 percent (Golovan et al. 2001). This impressive achievement will reduce one of the principal causes of aquatic eutrophication, algal growth, and fish kills in affected waters.

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