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CHINA's PLACE IN THE WORLD

Environmental impact of a giant

Cover Caption (*Nature*, June 30, 2005)

China's environmental problems dominate those of the world, not only because China contains a fifth of the world's people, but also because China's economy is so big and developing so rapidly. Through the expanding links of globalization, China is increasingly affecting and also being affected by the rest of the world. In a Feature this week, Jianguo Liu and Jared Diamond look at the effects of China's sweeping environmental change and socioeconomic challenges, synthesizing detailed literature that is scattered even for Chinese readers and largely inaccessible to western readers. The authors also outline the obligations that come with the growing global interdependence, and discuss why no one is exempt from playing a role in the future of China and the rest of the world. [Feature p. 1179]

On the cover, crowds on Nanjing Lu, Shanghai's famous shopping street where global influences are clear to see (Mark Henley/ Panos).

Elsewhere in the issue, Peter Aldhous reports on how China plans to cope with its exploding need for energy. [News Feature p. 1152]

FEATURE

China's environment in a globalizing world

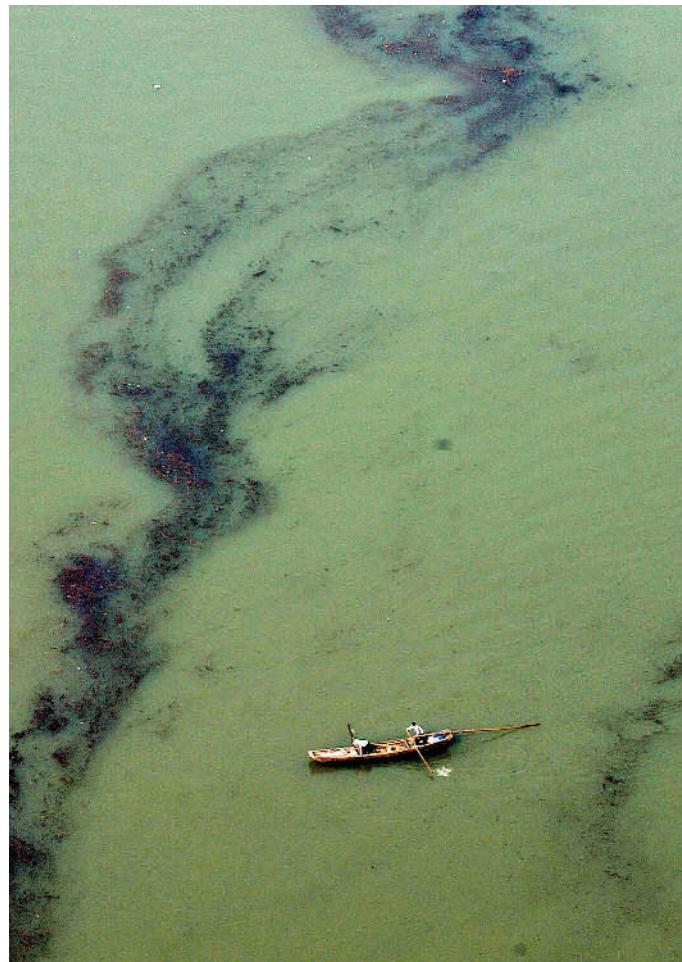
How China and the rest of the world affect each other.

Jianguo Liu and Jared Diamond

China is the world's most populous country and the fourth largest in area. Its economy, already huge, is growing at the fastest rate of any major nation. Its environmental problems are among the most severe of any major country, and are mostly getting worse.

Many Chinese, including its leaders, are aware of these problems and have tried to tackle them. Some things have improved, such as the air quality in Beijing and some other big cities. But such efforts have not matched the forces of environmental destruction, and have not prevented other indicators from further deterioration. The list of problems ranges from air pollution, biodiversity losses, cropland losses, depleted fisheries, desertification, disappearing wetlands, grassland degradation, and increasing frequency and scale of human-induced natural disasters, to invasive species, overgrazing, interrupted river flow, salinization, soil erosion, trash accumulation, and water pollution and shortages. These issues are causing serious economic losses, social conflicts and health costs within China.

China's environmental problems are also spilling over into other countries, while other countries affect China's environment through globalization, pollution and resource exploitation. China is already the largest contributor of sulphur oxides and chlorofluorocarbons to the atmosphere¹; its dust and aerial pollutants are transported eastwards to neighbouring countries and even North America; and it is one of the two leading importers of tropical rainforest timber², making it a driving force behind tropical deforestation. China accounts for 15% of the world fish catch and 33% of global fish and seafood consumption^{3,4}. A factor exacerbating many environmental problems in China is that, as a 'world factory', China exports products but consumes natural resources and leaves pollutants behind. Although China's per capita environmental impact is still far below that of developed



Global problem: pollution and floating rubbish at China's Three Gorges Dam exemplify the challenges for environmental protection across the world.

countries (Table 1), the proportionate increase in total human impact on the world's environments will be enormous if China's per capita impacts catch up with such countries.

After setting out some background information about China, we shall discuss the types of Chinese environmental impacts, their consequences for the Chinese, reciprocal impacts of China and other countries, China's future prognosis, and some recommendations. (Most references and data sources are listed in the Supplementary Information.)

Geography, population, economy and policy

Geography. China's environment is complex (Fig. 1, overleaf). It includes the world's largest and highest plateau, some of the world's

highest mountains, two of the world's longest rivers (the Yangtze and Yellow Rivers), many lakes, a long coastline and a large continental shelf. Its ecosystems range from glaciers and deserts to grasslands, wetlands, tropical rainforests, lakes and oceans (Supplementary Fig. 1). Within those ecosystems lie areas fragile for different reasons: for example, northwestern China's variable rainfall, winds and droughts expose its high-altitude grasslands to dust storms and soil erosion. Conversely, southern China is wet, but heavy rainstorms cause erosion on slopes.

Population. China's population of 1.3 billion people — 20% of the world's total — has more than doubled over the past half century (Supplementary Fig. 2). It is encouraging that the population growth rate has fallen from 2–3% per year between the 1950s and mid-1970s to less than 1% per year in recent years. This is due to a reduction in birth rate, thanks to factors such as the one-child policy. The death rate has remained quite stable for the past 25 years (Supplementary Fig. 3). China's fertility rate in 2003 (1.9 births per woman) (Supplementary Table 1) and population growth rate in 2003 (0.7%) were the fourth lowest among the 15 major countries that we tabulate (Table 1).

But another factor has worked in the opposite direction: the number of China's households grew almost three times as fast as its population during 1985–2000, because average household size decreased from 4.5 to 3.5 people^{5,6}. This alone gave China an extra 80 million households in 2000: more than the total number of households in Russia and Canada combined. All of our comparison countries except Pakistan and perhaps Russia also showed decreasing household size, but China's decrease, and hence its ratio of household number increase to population growth, was the second largest (Table 1). Because smaller households consume more resources per person⁵, China's rapid increase in household number and reduction in household size

JINYIN/IMAGECHINA

have had significant environmental consequences. For instance, while China's household size has been declining, its per capita house floor area has increased more than threefold from the late 1970s to the present (Supplementary Fig. 4).

China is also becoming more urban. From 1952 to 2003, while its total population 'merely' doubled, its proportionate urban population tripled from 13% to 39%. Hence the urban population increased sevenfold to more than half a billion (Supplementary Fig. 2). The number of cities increased fourfold to more than 660 (including more than 170 with at least one million residents), and the areas of existing cities grew hugely.

Economy. China's economy is big, and growing fast (Fig. 2). It ranks third in total gross domestic product (GDP) and has the highest growth rate, of three times the world average, of our 15 comparison countries (Table 1). It is the world's largest producer of steel, cement, aquacultured food and television sets, and is the second-largest producer of electricity and chemical textiles. From 1978 to 2003 its production of steel, cement, chemical fibre and colour TVs increased by 7, 13, 42 and 17,214 times, respectively (Supplementary Fig. 5). It is the largest consumer of fertilizer and accounts for 90% of the global increase in fertilizer use since 1981. As the second-largest producer and consumer of pesticides, China accounts for 14% of the world total and has become a net exporter. Production and consumption of these industrial and agricultural products leads to air, water and land pollution and other forms of environmental damage. But despite China's large total GDP and outputs of these various products, its per capita GDP and outputs are still much lower than those of many other countries — hence they still have a large potential to increase.

With increasing affluence, China's per capita consumption of meat, milk and eggs increased four-, four- and eightfold, respectively, between 1978 and 2002; its egg consumption now equals that of rich nations. This means more agricultural wastes, animal droppings (already four times the output of industrial solid wastes), fish droppings, fish food and fertilizer for aquaculture, tending to increase terrestrial and aquatic pollution.

China's transportation network and number of vehicles have grown explosively (Fig. 3). In 1994, after the number of motor vehicles had increased to six times the 1980 figure, China decided to make car production one of its four 'pillar industries' to stimulate economic growth, with the goal of increasing production (especially of cars) by another factor of four by 2010. This would make China the world's third-largest vehicle manufacturer, after the United States and Japan — with obvious implications for highway expansion at the expense of arable land, greater dependence on imported oil, and the recently improved but still poor air quality in cities such as Beijing.

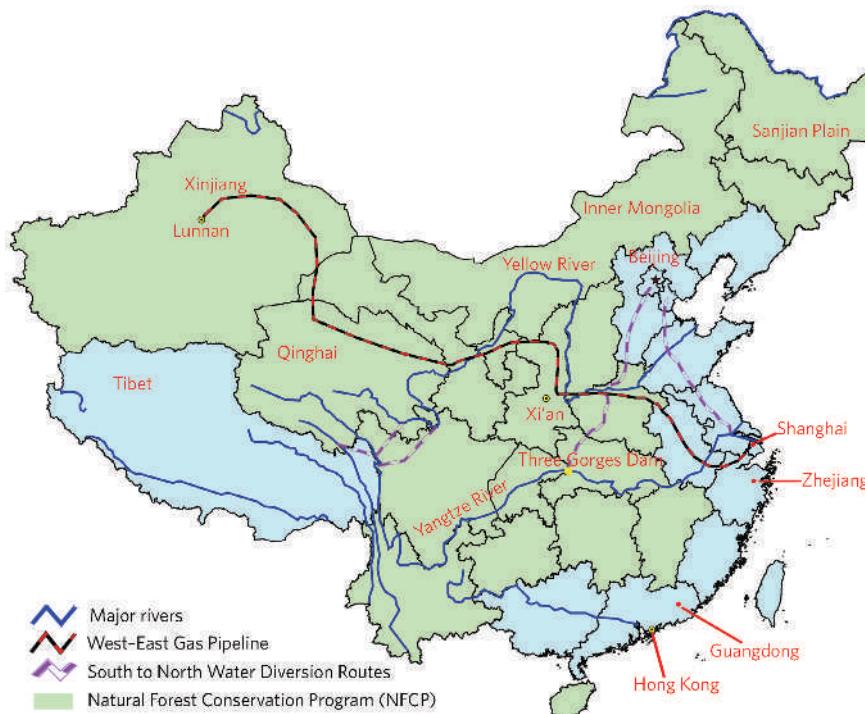


Figure 1 | China. Map of China showing locations of selected projects and places discussed in the text.

Behind these impressive statistics lurks a mixed picture. In sectors of the economy facing strong foreign competition and receiving foreign investment, such as automobile production and fuels, Chinese industry is almost as efficient as that in developed countries. Since 1980, the reduction in China's energy intensity (energy consumption per dollar of GDP) has been unprecedented among developing countries, thanks to energy conservation, phasing-out of inefficient old facilities, adoption of modern technologies and shifts from energy-intensive heavy industry to less intensive light industry and service sectors.

In contrast, much of China's economy — such as coal-mining and cement, paper and chemical production — still rests on outdated, inefficient or polluting technology, and overall industrial energy efficiency is only half that of the developed world (Supplementary Fig. 4). China's paper production consumes more than twice as much water as that in developed nations. Its irrigation relies on inefficient surface methods that waste water, cause eutrophication and wash nutrients out of the soil and sediment into the rivers. China's coal-based production of ammonia, required for fertilizer and textile manufacture, consumes 40–80 times more water than natural-gas-based ammonia production⁷ (because its gas reserves are far from ammonia production centres), although this situation is changing, as discussed below.

Because energy is essential for China's rapid economic development, China is the second-largest energy consumer, after the United States. But China's per capita use of energy in 2001 was only a ninth of that in the United States, and half of the world average. China ranks eighth in that respect among the

15 major countries (Supplementary Table). China leads the world in the production and consumption of coal⁸, with 25% of the world's total. It is the country's primary energy source and the main cause of its air pollution and acid rain, although coal use has declined since the 1950s and has fluctuated in recent years as the use of oil, natural gas and hydroelectric power has increased (Supplementary Fig. 6). In 2003 China overtook Japan to become the second-largest consumer of petroleum after the United States⁹. Although solar and wind power are potentially significant renewable energy sources, hydroelectricity will become more important over the next decade, particularly with the expected completion of the controversial 18.2-gigawatt Three Gorges Dam project in 2009 (Fig. 1).

Natural gas accounts for just 3% of China's energy consumption today. But its use may increase fourfold by 2010 through increases in production from domestic reserves (53.3 trillion cubic feet at the beginning of 2004), and through imports, by pipeline and in the form of liquified natural gas (LNG). The world's longest gas pipeline, the West-to-East Pipeline, began construction in July 2002 to carry gas 3,800 km from the largest reserves in western and north-central China to Shanghai on the east coast (Fig. 1). It will be completed in 2005 (ref. 9). A pilot LNG project is under construction in the economic hotbed of Guangdong Province and will provide 4 billion cubic metres of natural gas annually (Fig. 1).

Another distinctive feature of China's economy is its widely distributed small-scale rural industry: township and village enterprises (TVEs) with an average of six employees (Supplementary Fig. 7). They account for a third of Chinese production and half of its exports but

Table 1 | Population, economy and environmental conditions of China and 14 other major countries*

Country	Population total (millions, 2003)	Annual population growth rate (%), 2003)	Ratio of growth in household numbers to population growth (1985–2000)	Average annual GDP growth (%), 1999–2003)	Ranking of environmental sustainability index (1–142)** 2002	CO ₂ emission (metric tons per capita, 2000)	Total CO ₂ emission (million metric tons, 2000)	Per capita ecological footprint (global ha per person, 2001)	SO ₂ per populated area (1,000 metric tons per km ² , 2000)
China	1,288	0.7	2.7	8.0	129	2.2	2,780	1.5	2.7
Bangladesh	138	1.7	1.5	5.2	86	0.2	30	0.6	0.7
Brazil	177	1.2	1.9	1.6	20	1.8	310	2.2	0.4
India	1,064	1.5	1.2	5.8	116	1.1	1,120	0.8	1.2
Indonesia	214	1.3	1.8	2.0	100	1.3	270	1.2	0.4
Japan	127	0	6.1	1.3	78	9.3	1,180	4.3	1.0
Malaysia	25	1.9	1.3	4.9	68	6.2	140	3.0	1.6
Mexico	102	1.4	1.9	2.4	92	4.3	420	2.5	1.0
Nigeria	136	2.1	2.7	4.1	133	0.3	40	1.2	0.2
Pakistan	148	2.4	0.4	3.4	112	0.8	110	0.7	0.3
Philippines	82	1.9	1.4	4.3	117	1.0	80	1.2	0.9
Russia	143	-0.4	No data	6.7	72	9.9	1,440	4.4	0.9
Thailand	62	0.6	2.6	4.7	54	3.3	200	1.6	1.1
United States	291	0.9	1.6	3.2	45	19.8	5,590	9.5	1.7
Vietnam	81	1.1	1.5	6.5	94	0.7	55	0.8	0.3
World	6,271	1.2	1.6	2.5	—	4.0	24,210	2.2	1.7

*The most populous countries in the world, with at least 100 million people each, plus the four next most populous countries (Malaysia, Philippines, Thailand and Vietnam) in Southeast Asia.

**1 = most sustainable, 142 = least sustainable, among 142 countries ranked.

contribute disproportionately to pollution^{1,10}. Technology levels in some TVE sectors are advanced, but they are low in other sectors such as brick-making, coal-mining, cement-making, paper production, pesticide and fertilizer manufacturing, coking and metal-casting, which consume more resources and produce more pollution than larger state-owned enterprises.

Policy. China's leaders once believed that humans could and should conquer nature, and that only capitalist societies suffered from environmental damage¹¹. Such thinking began to change in 1972, when China sent a delegation to the First United Nations Conference on the Human Environment¹¹. In 1973 the government's Leading Group for Environmental Protection was established, which evolved in 1988 into the National Environmental Protection Agency, and in 1998 became the State Environmental Protection Administration (SEPA)¹². China declared environmental protection a basic national principle in 1983, laid out a broad strategy to achieve sustainable development in 1994, and in 1996 developed its first five-year plan on environmental protection¹². In 2003, the government proposed a new development concept emphasizing humanism and attempting to achieve sustainable development and harmony between man and nature, as well as coordinated socio-economic progress among various regions and with foreign countries¹³. China has also participated in international treaties such as the Convention on Biological Diversity and the UN Millennium Development Goals, which include poverty alleviation, environmental protection and sustainable development. More than 100 environmental policies, laws and regulations have been passed. These seem

excellent on paper, but putting them into practice is not easy. In reality, although there has been much effort to control environmental degradation, economic development often takes priority at the local level and is still the main criterion for judging government officials' performance.

Environmental impacts

There was large-scale deforestation in China several thousand years ago. Following the Second World War and the Chinese Civil War, the peace of 1949 brought more deforestation, overgrazing and soil erosion. The Great Leap Forward in 1958–1960 saw a dramatic increase in the number of factories — there was a fourfold increase in 1957–1959 alone — along with pollution and more deforestation, to obtain the fuel for inefficient backyard steel production. From the 1960s until the mid-1970s, pollution grew, as many factories were relocated to the interior from coastal areas considered militarily vulnerable. Since economic reform began in 1978, environmental degradation has continued to accelerate^{10,14}, largely due to rapid industrialization, including TVEs.

China faces greater environmental challenges than other major countries. Of the 142 countries for which environmental sustainability was evaluated, China ranked 129th, higher only than Nigeria among our 15 comparison countries (Table 1). In per capita ecological footprint (a measure of human natural resource consumption and waste output), China is below the world average (Supplementary Table), but its total ecological footprint is the second largest in the world after the United States, owing to its population size.

China's environmental problems can be

summarized under five categories: air, land, fresh water, oceans and biodiversity.

Air. China's air quality is generally low. Three out of four city dwellers live below China's air-quality standard¹⁵. Acid rain fell on a quarter of its cities for more than 60% of rainy days per year in the 1990s and now affects a quarter of China's area, making it among the world's most severely affected countries⁸.

A major cause of these problems is the increasing output of industrial waste gases (Supplementary Fig. 8). After declining or levelling off in 1998, emissions of SO₂ and possibly of dust and industrial soot resumed climbing in 2003. In 2000 China led the world in SO₂ emissions (Table 1) and ranked third for NO_x emissions in populated areas among the major countries (Supplementary Table).

On the other hand, several air-quality indicators have shown positive signs. More industries are achieving emission standards. Among the 47 key cities for environmental protection, 11 and 29 have exceeded the national air-quality standards for SO₂ and particulate concentrations, respectively, including Beijing¹⁵.

Land. Soil erosion affects 19% of China's land area, one of the highest figures for any country¹⁰. Erosion is especially devastating on the Loess Plateau on the middle stretch of the Yellow River, which is about 70% eroded, and increasingly on the Yangtze River, whose sediment discharge from erosion exceeds the combined discharges of the Nile and Amazon, the world's two longest rivers. By filling up rivers (as well as reservoirs and lakes), sediment has shortened China's navigable river channels by 56% between 1949 and 1990, and has restricted the size of ships that can use them. Soil quality and fertility, as well as soil

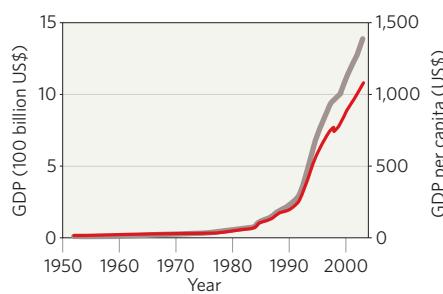


Figure 2 | Chinese gross domestic product (GDP). Growth of national (brown line) and per capita (red line) GDP.

quantity, have declined, in part due to long-term fertilizer use plus pesticide-related declines in soil-renewing earthworms. Salinization has affected 9% of China's lands, mainly due to poor design and management of irrigation systems. This is one environmental problem that government programmes have made good progress in combating and starting to reverse. Desertification, due to overgrazing and land reclamation for agriculture, has affected more than a quarter of China, especially in Qinghai Province and the Inner Mongolia Autonomous Region.

All of these soil problems have joined urbanization and land appropriation for mining, forestry and aquaculture in reducing China's cropland. This threatens food security¹⁶, because while cropland area has been declining, population and per capita food consumption have been increasing, and the area of cultivatable land is limited. Between 1991 and 2000, cropland declined to the point where there is now only 0.1 ha per person, barely half of the world's average. Unrecycled and unused industrial waste and domestic trash are dumped into open fields around most cities, polluting soil and taking over or damaging 100,000 km² of cropland¹⁴. Industrial solid-waste production has risen, but waste release is declining because of increased recycling (Supplementary Fig. 9).

China is one of the world's most forest-deficient countries, with only 0.1 ha of forest per person, compared with a world average of 0.6 ha. Forests cover only 18% of China's land area, compared with 64% of Japan's and 30% on average (Supplementary Table). Although government programmes have increased the area of single-species tree plantations and thereby the total forested area (Supplementary Fig. 10), natural forests, especially old growth, have shrunk. Deforestation is a major cause of soil erosion and flooding in China. The 1998 floods that affected 240 million people shocked the government into action, including the banning of any further logging of natural forests in upper and middle reaches of watersheds of major rivers such as the Yangtze and Yellow Rivers.

The other most serious forms of land degradation are the destruction of grasslands and wetlands. China is second only to Australia

in the extent of its natural grasslands¹, which cover 40% of its area¹⁰, mainly in the drier northwest. However, per capita grassland area is less than half of the world's average. Grasslands have been declining at approximately 15,000 km² a year since the early 1980s. Furthermore, grasslands have been severely degraded by overgrazing, climate change, and mining and other types of development; 90% of China's grasslands are now considered degraded. Grass production per hectare has decreased about 40% since the 1950s, and weeds and poisonous grasses have thrived at the expense of high-quality species. Grassland degradation has implications beyond its usefulness to China's farmers, because the grasslands of the Tibetan Plateau contain the headwaters for the major rivers of India, Pakistan, Bangladesh, Thailand, Laos, Cambodia and Vietnam, as well as of China (Supplementary Fig. 1).

There are approximately 660,000 km² of wetlands in China, about 10% of the world's total. However, wetlands have been decreasing in area through conversion to cropland and other uses. Three-fifths of the swamps in the Sanjian Plain in the northeast, the area with China's largest freshwater swamps, has already been drained to become farmland. At the present rate the rest will disappear within 20 years¹⁰. As a result, natural wetlands account for only 3.8% of China's territory, less than the global level of 6.0%. Wetland function has also declined, with greater water-level fluctuations and reduced capacity to mitigate floods and to store water. Wetlands face other major threats, including increased pollution, insufficient funding, and ineffective laws and regulations.

Fresh water. Water quality in most Chinese rivers and groundwater sources is poor and declining, owing to industrial and municipal wastewater discharges, plus agricultural and aquacultural run-offs of fertilizers, pesticides and manure, causing widespread eutrophication⁷. The amount of waste water discharged has increased steadily (Supplementary Fig. 11). About 75% of lakes are polluted. The Guanting Reservoir in Beijing was declared unfit for drinking in 1997. The percentage of industrial waste water treated has been increasing, but only 20% of domestic waste water is treated, compared with 80% in the developed world.

Shortages and waste exacerbate China's water problems. China's per capita quantity of fresh water is only a quarter of the world average. Water resources are spread unevenly, with northern China having only one third of the per capita quantity of southern China. This underlying water shortage, plus wasteful use, causes over 100 cities to suffer from severe shortages and even halts industrial production. Of the water required for cities and for irrigation, two-thirds depends on ground water pumped from wells tapping aquifers. However, those aquifers are becoming depleted, letting sea water enter them in most

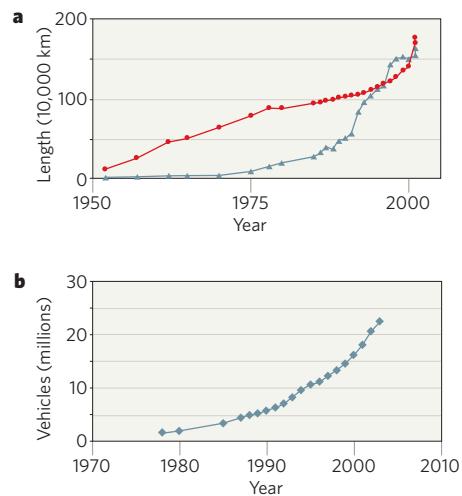


Figure 3 | Transport in China. a, Length of highways (red line) and number of civic aviation routes (green line). b, Number of vehicles.

coastal areas, and causing subsidence in some cities as the aquifers are drawn down. China already has the world's worst cessation of river flows, and this is increasing because people continue to draw water from rivers. There were flow stoppages on the lower Yellow River in 20 of the years between 1972 and 1997, and the number of days without any flow increased from 90 days in the 1980s to an astonishing 230 in 1997 (ref. 10).

Pollution and overfishing are degrading freshwater fisheries because fish consumption is rising steeply. Per capita fish consumption has increased nearly fivefold in the past 25 years¹⁷, and there is a growing export of fish, molluscs and other aquatic species. As a result, the white sturgeon has been pushed to the brink of extinction, previously abundant fish species such as the yellow croaker and hairtail must be imported, the catch of wild fish in the Yangtze River has declined by 75%, and that river had to be closed to fishing for the first time in 2003 to protect fishery resources from collapse. To meet demand for fish products, production of aquacultured freshwater fish has increased steeply (Fig. 4).

Oceans. China has a sea area of 3 million km² and has jurisdiction over the vast continental shelves and exclusive economic zones up to 200 nautical miles off its coasts. Almost all coastal seas are polluted¹, mainly by pollutants from the land, plus oil spills and other marine activities. In 2004 the State Oceanic Administration recorded 867 main outlets discharging pollutants into the sea. In 2003 alone, 20 of those outlets discharged approximately 880 million tonnes of sewage water, containing 1.3 million tonnes of pollutants, including toxic substances such as lead, cadmium and arsenic. On average, there are 90 red tides in China's seas each year, up from only one every five years in the 1960s (Fig. 5). Pollution and overfishing have hit fishery stocks. Natural harvests have significantly declined — the formerly robust Bohai prawn harvest has

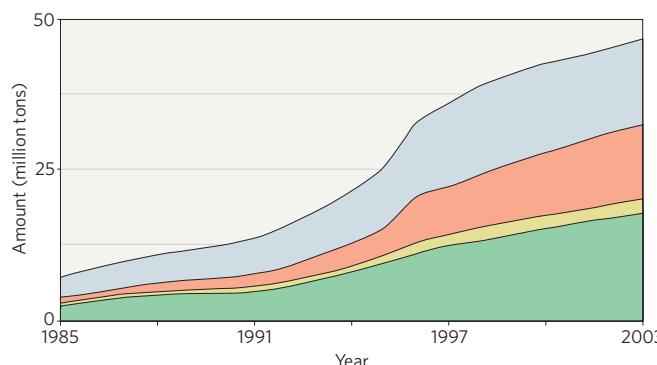


Figure 4 | Chinese aquatic production. Mass of cultured freshwater (green), wild freshwater (yellow), cultured marine (orange) and wild marine (grey) products.

dropped by 90% — and production of aquacultured seafood has increased (Fig. 4). China's area of mangrove declined by 73% from the early 1950s to 2002.

Biodiversity. China has more than 10% of the world's vascular plant and terrestrial vertebrate species¹⁸. However, 15–20% of China's species — including the giant panda — are now endangered, largely by human activities¹. Many distinctive rare animals and plants, such as Chinese alligators, are at risk of extinction. To protect biodiversity, the Chinese government had set up almost 2,000 nature reserves by the end of 2003, mostly within the past 20 years (Fig. 6), plus many zoos, museums, botanical gardens, wildlife breeding centres, and gene and cell banks. The reserves cover 14.4% of China's territory, a percentage higher than the world average and than the percentages of most developed countries. Nevertheless, these reserves must be better managed and more strategically important reserves are needed¹⁸.

The flip side of these declines in native species has been rises in both terrestrial and aquatic invasive species: more than 400 by 2004. Examples include ragweed (a plant native to North America), water hyacinth and Amazonian snails¹⁹. Some of those invaders have become pests and weeds, inflicting heavy economic damage on Chinese agriculture, aquaculture, forestry and livestock production: almost US\$14.5 billion (1.4% of China's GDP in 2000) in 2000 alone. Most invasive species were brought into China, intentionally or unintentionally, by international trade and other activities. In Shanghai harbour alone, between 1986 and 1990, almost 200 foreign weed species were found in imported materials carried by 349 ships from 30 countries.

Consequences for China's people

China's environmental degradation is harmful not only to its earthworms and yellow croakers, but also to its people. The consequences for Chinese people can be partitioned into socio-economic losses, health costs, and the effects of more frequent and damaging natural disasters.

Socioeconomic losses. Starting with small examples and proceeding to larger ones: \$72 million per year is being spent to curb

of crops and forests due to acid rain amount to about \$730 million per year²². More serious is the \$6 billion cost of the 'green wall' of trees being built to shield Beijing against sand and dust, the annual direct losses due to desertification (\$7 billion), and the \$7 billion per year in losses created by several major alien species other than alligator weed. Even bigger numbers are the one-off cost of the 1996 floods (\$27 billion, but still cheaper than the 1998 floods) and the annual losses due to water and air pollution (\$54 billion)^{7,10}.

The losses from pollution and ecological damage ranged from 7% to 20% of GDP every year in the past two decades²³. Besides heavy economic losses, pollution and resource competition have triggered numerous social clashes in China, including 18 conflicts over forest resource management in southwestern China compiled by the Food and Agriculture Organization of the United Nations in 2001. Similarly, water shortages in the Yellow River have triggered 'water wars' between people on the river's upper and lower reaches, between people on opposite sides of the river, and between backers of industrial, agricultural and ecological needs.

Health costs. Environmental pollution imposes further costs through its impact on human health. From 1996 to 2001, China's spending on public health increased by 80%, or more than 13% per year (from \$35 billion in 1996 to \$63 billion in 2001)²⁴, in part to cope with environmental problems. About 300,000 deaths per year are attributed to air pollution⁷. Average blood lead levels in Chinese city dwellers are nearly double those considered to be dangerously high and to endanger children's mental development. The risk of respiratory disease increases with the outdoor concentration of total suspended particles. Even short-term exposure to air pollution can result in low infant weight and increased morbidity and mortality²⁵.

Natural disasters. China is noted for the frequency, number, extent and impact of its natural disasters. Human actions have made some of these more frequent, especially dust storms, landslides, droughts and floods¹⁰. Overgrazing, erosion, grassland degradation,

desertification and partly human-caused droughts have led to more frequent, and more severe, dust storms. From AD 300 to 1949, dust storms struck northwestern China on average once every 31 years; since 1990 there has been one almost every year. The huge dust storm of 5 May 1993 killed a hundred people. Recent increases in droughts are believed to be due to deforestation that has interrupted the water cycle, and perhaps also due to the decrease in surface water resulting from draining and overuse of lakes and wetlands. Droughts damage about 160,000 km² of cropland each year, double the area damaged in the 1950s. Flooding has greatly increased because of deforestation; the 1996 and 1998 floods were the worst in recent memory. Alternating droughts and floods have become more frequent and are more damaging than either disaster alone, because droughts destroy vegetation, and then flooding of bare ground produces worse erosion.

How China and the world affect each other

China and the rest of the world have become closely interconnected. China's large territory and population guarantee environmental impacts on the rest of the world. The rest of the world increases these impacts by means of the trade and investment that fuel China's rapid economic growth. Although international trade was negligible before 1980 (Fig. 7a), and although foreign investment in China was negligible as recently as 1991 (Fig. 7b), both have recently accelerated almost exponentially. There was a 40-fold increase in international trade between 1978 and 2003.

Since 2002, China has overtaken the United States to receive the most foreign investment annually of any country (Supplementary Table). The Chinese government has encouraged foreign investment through the development of 'special economic zones' in which foreign investors receive preferential tax and tariff treatment. Environmental impacts of foreign investment and international trade may be either a positive or negative^{26,27}, as we will now show.

Beneficial and harmful imports. Much of the products, technologies, knowledge and financial support imported into China is environmentally benign or strongly beneficial. Between 1992 and 2004 the World Bank provided more than \$22 billion to China, of which approximately 10% was used for environment-related projects. Many of the imported raw materials and products help China reduce its consumption of domestic natural resources and its pollutant discharge. For example, agricultural imports let China decrease its use of fertilizers, pesticides, water and low-productivity cropland; and oil and natural-gas imports let China reduce pollution from burning coal. Since 1993, China's oil consumption has exceeded its oil production, and the gap is widening⁹. From 1980 to 2002, the value of China's imported primary

goods increased from \$7 billion to \$49 billion. On the other hand, some imports are unequivocally harmful to China's environment. Along with the invasive species mentioned earlier, another example is imported garbage. Some developed countries export untreated garbage to China, including waste containing toxic chemicals. In addition, China's expanding manufacturing economy accepts garbage and scrap that could be a cheap source of recoverable raw materials. As just one example, in September 2002 a customs office in Zhejiang Province recorded a 360-tonne shipment of electronic garbage from the United States, consisting of scrap electronic equipment and parts such as broken or obsolete TV sets, computer monitors, photocopiers and keyboards. Statistics on the total amount of such garbage imported are incomplete, but estimates show an increase in direct imports from 1 million to 11 million tonnes from 1990 to 1997 (ref. 28), and garbage shipped via Hong Kong (Fig. 1) also increased from 2.1 million to over 2.7 million tonnes per year from 1998 to 2002. Although some people view importing harmful garbage as part of normal international trade, the Chinese government prohibits it and has been trying to stop it.

Even worse than garbage, while many foreign companies have helped China's environment by transferring advanced technology to China, others have hurt it by transferring pollution-intensive industries (PIIs), including technologies illegal in the country of origin. As of 1995, China was home to an estimated 16,998 PII firms with a combined industrial product of about \$50 billion²⁸. For financial and various other reasons, it has often been impossible for China to adopt the advanced technology standards of developed nations, which in turn profit and gain competitive advantage by exporting outdated or even illegal technologies. Many Chinese officials and economists believe that PIIs benefit China by raising economic efficiency and reducing pollution in the long run. But PIIs cause severe damage to the environment, as well as to human health and socioeconomic well-being, and some of the damage, such as biodiversity losses, is irreversible.

Exports causing damage at home. Export trade is a major cause of China's increasing pollution, because products go abroad but pollutants stay behind. Most of China's exports are primary goods or manufactured products that create heavy pollution and require intensive resource uses. For instance, from 1989 to 2002 the value of goods exported by heavily polluting TVEs increased 31-fold, including a 22-fold increase in textiles and an 18-fold increase in food²⁹.

Invasive species exported. China's high native biodiversity means that China exports many invasive species. The three best-known pests of North American tree populations — the chestnut blight, the misnamed 'Dutch'

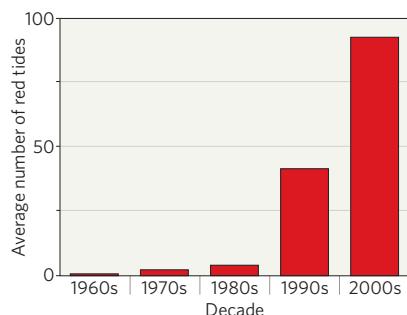


Figure 5 | Average annual number of red tides in Chinese seas.

elm disease, and the Asian long-horned beetle — originated in China or somewhere nearby in East Asia¹⁹. China's grass carp is established in rivers and lakes of 45 US states, where it competes with native fish species and changes the plant, plankton and invertebrate communities.

Exports in the atmosphere. China became the world's largest producer and consumer of ozone-depleting gases, such as chlorofluorocarbons, after developed countries phased them out in 1995 (ref. 1). China already leads the world in the production of sulphur oxides, with an output double that of the United States. China's per capita production of CO₂ and NO_x is far below that of rich countries, or for CO₂ even below Mexico, Russia and Thailand (Table 1 and Supplementary Table). But China's huge population is still the second-largest contributor of CO₂, emitting approximately 12% of the world's total.

Aerial particles from China also affect the regional and global atmosphere. Propelled eastwards by prevailing winds, pollutant-laden dust, sand and soil from China's deserts, degraded pastures and fallow farmland blow to Korea, Japan, Pacific islands and across the Pacific within a week to the United States and Canada³⁰. The aerial particles result from China's coal-burning economy, overgrazing and soil erosion. Together with affected countries and the international community, China has been trying to reduce aerial particles as well as greenhouse gases and ozone-depleting substances.

Exported deforestation. China ranks third in the world in timber consumption¹. Because wood provides almost all the raw material for the paper and pulp industry, and also panels and lumber for construction, there is a growing gap between China's demand for wood products and its domestic supply, especially since the national logging ban that followed the floods of 1998. China's wood imports, both from tropical and temperate countries, have increased sixfold since the ban³¹. As an importer of tropical lumber, China now stands second only to Japan, which it is rapidly overtaking. With China's entrance into the World Trade Organization (WTO), timber imports are expected to increase, because tariffs on wood products are about to be reduced from a rate of 15–20% to 2–3%. In effect, this means

that China, like Japan, will be conserving its forests by exporting deforestation³¹, already at or close to devastating levels in several countries, including Malaysia, Papua New Guinea and Australia.

The future

What does the future hold for China? Environmental problems are accelerating, and attempted solutions are accelerating, but which horse will win the race?

Generalized dangers. A pessimist will note many dangers already at work in China. Economic growth, rather than environmental protection or sustainability, is still China's priority in practice. Despite a fall in population growth rate, the number of Chinese is projected to reach almost 1.5 billion by 2030. The projected drop in household size to 2.2 people⁶ by the year 2030 alone would add over 250 million new households — more than the total in the entire Western Hemisphere in 2000 — even if China's population size remained constant.

Public environmental awareness is low, in part because China's investment in education is less than half that of developed countries as a proportion of gross national production. Despite holding 20% of the world's population, China's educational funding accounts for only 1% of world investment. Most parents cannot afford to send their children to university, because one year's tuition would consume the average salary of one city worker or three rural workers.

Chinese environmental laws and regulations were written largely piecemeal, lack effective implementation and evaluation of long-term consequences, and need a systems approach. Prices for important environmental resources are set so low as to encourage waste: one could buy 10–100 tonnes of Yellow River water for use in irrigation for the cost of a small bottle of spring water¹⁰. Land is owned by the government, but may be used by many different peasants within a relatively short period, so peasants lack incentives to make long-term investments in their land or to take care of it.

Specific dangers. The Chinese environment also faces many specific dangers. The number of cars is rising, and croplands and natural wetlands are disappearing. The harmful consequences of this will accumulate. With rising affluence, and hence meat and fish consumption, environmental problems from meat production and aquaculture, such as pollution from animal and fish droppings and eutrophication from uneaten fish food, will increase. Already, China is the world's largest producer of aquaculture-grown food, and is the sole country in which aquaculture provides more fish and aquatic foods than wild fisheries.

China is hosting the world's three biggest development projects (Fig. 1), all of which are expected to cause severe environmental problems. The Three Gorges Dam on the Yangtze River — the world's largest dam, begun in

1993 and projected for completion in 2009 — aims to provide electricity, flood control and improved navigation at a cost of \$30 billion, social costs of uprooting millions of people, and environmental costs associated with landslides, water pollution, soil erosion, biodiversity losses and the disruption of the ecosystem of the world's third-longest river³². Still more expensive is the South-to-North Water Diversion Project, which began in 2002 but is not scheduled for completion until around 2050. It is projected to cost \$59 billion, to spread pollution, and to cause water imbalance in the Yangtze. Even that project will be exceeded by the ongoing development of western China, comprising over half of the country's land area and viewed by China's leaders as the key to national development.

Increased world impact. Potentially more important than all of these other impacts is a further consequence of China's having the world's largest population and fastest-growing economy. Total production or consumption is the product of population size times per capita production or consumption rate. China's total production and consumption are already high, because of its huge population, despite its per capita rates still being very low. For instance, the per capita consumption rate of four major industrial metals (steel, aluminum, copper and lead) is only 9% of that of the leading industrial countries. But China is rapidly becoming a developed-world economy. If China's per capita consumption rates do reach such levels, and even if populations, production and consumption rates everywhere else remained unchanged, those rate increases alone would translate into a 94% increase in total world production or consumption in industrial metals, and a 106% increase in the case of oil. In other words, China's achievement of developed-world consumption standards will approximately double the world's human resource use and environmental impact. But it is doubtful whether even the current human resource use and impact on the world can be sustained. Something has to give, or change. This is why China's environmental problems are the world's.

Hopeful signs. There are also important sources of optimism. China is increasingly assuming responsibilities on the world stage by participating in environmental treaties. Many environmental laws, policies and regulations are being developed or improved. The Chinese public's environmental awareness is rising. China has been pushing hard for cleaner production and sustainable development. Some environmental and product standards have reached developed-world levels. Energy intensity is declining. Technologies for production and for treating environmental waste are improving.

China has promoted the use of ecological principles in production and pollution control, such as ecological agriculture and some traditional environmentally friendly technologies.



Figure 6 | Chinese nature reserves. Shown by number (brown line) and area (red line).

For example, the southern Chinese practice of raising fish in irrigated rice fields recycles fish droppings as fertilizer, increases rice production, uses fish to control insect pests and weeds, decreases herbicide, pesticide and synthetic fertilizer use, and yields more dietary protein and carbohydrate, without increasing environmental damage.

Both WTO membership and the impending 2008 Olympic Games in Beijing have made the Chinese government pay more attention to environmental problems. To reduce air pollution in Beijing, the city government ordered that vehicles be converted to allow the use of natural gas and liquefied petroleum gas. China has phased out leaded petrol in little more than a year, something that took Europe and America many years to achieve. New cars must meet the exacting emissions standards prevailing in Europe.

Also encouraging is the 1998 ban on logging and the start of the Natural Forest Conservation Program (Fig. 1) to reduce the risk of further flooding³³. Since 1990, China has combated desertification on 24,000 km² of land by reforestation and fixation of sand dunes¹⁰. The Grain-to-Green programme, begun in 2000, gives grain and cash subsidies to farmers who convert cropland to forest or grassland, and is reducing the use of environmentally sensitive steep hillsides for agriculture. By the end of 2003, 79,000 km² of cropland had been returned to forest or grassland³⁴. By the end of this programme in 2010, approximately 130,000 km² of cropland are expected to be converted³⁵, making it one of the largest conservation programmes in the world. China is also designing and adopting a green accounting system that includes environmental costs in the calculation of gross domestic product (or Green GDP).

Recommendations and outlook

How can China turn its environmental trend from deterioration to improvement? Many specific recommendations follow directly from our review. For example, China could import technologies for decreasing fertilizer and pesticide use, reducing motor-vehicle exhaust pollution, improving efficiency of paper and ammonia production and irrigation systems, treating waste water, conserving water and other resources, promoting the use of cleaner energy, and stopping draining of wetlands. We also offer six broader sets of recommendations:

1. The impressive body of environmental laws and regulations that exists largely on paper should be implemented and enforced. Because some governmental officials have interests in companies that damage the environment, it is hard for them to enforce environmental policies. To avoid conflicts of interest, regulation of environmental resources should be transferred to the SEPA from agencies responsible for developing those resources. The SEPA should have the power to close down heavy polluters, because many local officials protect polluters to boost GDP, the main criterion for their promotions. Selection and promotion of government officials should consider environmental protection as well as economic development. The relatively small number of environment enforcement officials should be increased and they should be better trained.

Lack of enforcement is also due to lack of funding. China has a lower GDP than Japan and the United States (Supplementary Table) but more serious environmental problems, so it needs proportionally higher environmental investment. Hence China's budget for environmental protection should rise from its current 1.2% of GDP to rich-nation levels (1.5% in Europe and Japan, and 2% in the United States) or higher. A high investment would make sense on economic grounds alone, by eliminating much of the losses caused by environmental damage.

2. As China moves towards a more market-based economy, more market tools should be applied to environmental issues. Possible examples include: eliminating subsidies for environmentally damaging industries, such as coal; setting fair prices for ecosystem services that are now grossly underpriced, such as water; enhancing emissions trading to reduce pollution; imposing more environmental taxes, such as a higher consumption tax on cars; compensating residents in and around nature reserves, such as those for the endangered giant pandas; and incorporating direct and indirect environmental costs (such as pollution) as well as values of ecosystem services (such as of wetlands) into accounting from local to national levels.

3. Focus attention not only on population size, whose growth has already slowed, but also on household number, size and consumption⁵. The government should provide incentives for sharing household resources.

Two major factors in the dramatic increase in household numbers and reduction in household size are divorces and declines in the number of households where several generations live under one roof. Many older people now live alone, rather than with their children and grandchildren. Divorces have increased sharply owing to simplified divorce procedures and wider societal acceptance of divorce. In 2004, more than 1.6 million couples filed for divorce, up 21% from 2003. Divorces hurt the environment because they double the number

of households and reduce the household size, increasing per capita resource consumption and waste. Government-supported mediation, counselling and a mandatory waiting period of one month or more for divorce would help people to think more seriously about divorce. Incentives should be provided to encourage sharing of resources through schemes such as co-housing (conceived in Denmark) and eco-villages (founded in the United States and Russia). These provide not only socioeconomic benefits to co-habitants, but also help to increase the efficiency of resource use and reduce per capita ecological footprints.

4. Investment in education should be increased significantly. Besides ameliorating China's environmental problems by increasing environmental awareness and decreasing human fertility, educational investments would yield economic benefits by upgrading the skills of China's work force. Better elementary and high-school education would also help more children in biodiversity-rich and environmentally fragile regions, such as western China, to go to college and reduce human pressure on sensitive ecosystems, because college graduates have better opportunities to find jobs and settle down elsewhere.

5. More effective measures should be taken to conserve biodiversity. Polluted air and water can be cleaned up, but lost species and genetic materials cannot be restored. Furthermore, biodiversity offers goods and services essential for human survival, including clean, nutritious food, water and air purification, oxygen generation, mitigation of climate change, pollination of crops and many other plants, control of crop pests, and carbon storage. For example, the naturally sterile male wild-rice variety discovered in China in 1970 has made high-yield hybrid rice possible, and with it the second green revolution.

6. Other countries can, and should, help China to protect its environment. Importing countries contribute to China's pollution. Per capita resource consumption and pollutant outputs are still much lower in China than in developed countries, so China has the moral right, as well as the power, to develop. But the resulting environmental impacts would extend beyond China's borders, making it in other countries' interests to help China. One way would be to support Chinese environmental non-governmental organizations (NGOs), because in China, as elsewhere, those problems exceed governments' capacity to solve them unaided. China has more than 2,000 fledgling environmental NGOs, but most are small, poorly funded, isolated and in need of help. Together with the Chinese government, the international community could help NGOs to increase the public's environmental awareness, contribute to governmental policy, and monitor policy implementation. Other possibilities include: training environmental planners and managers; sharing methods for conflict resolution; transferring environmen-

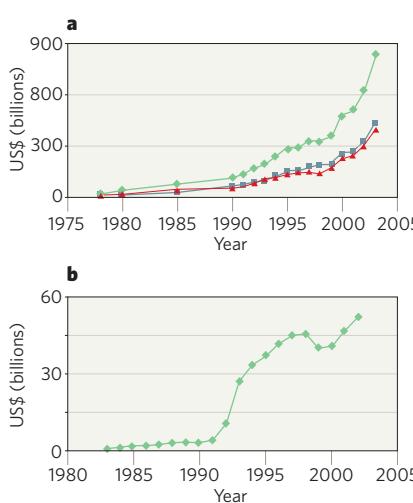


Figure 7 | Trade and foreign investment in China. **a**, Imports (red line), exports (grey line) and total imports and exports (green line); **b**, Foreign direct investment.

tally benign technologies, such as ones for cleaner manufacturing, water conservation and waste treatment; and transferring high-efficiency technologies, which would yield the additional advantage of reducing the already growing competition between China and other countries for energy and for other global resources.

How will it all end up? China is lurching between accelerating environmental damage and accelerating environmental protection. Its large population and booming economy mean that China's lurches carry more momentum than those of other countries. In the past two decades, China has created an economic miracle. We hope that, over the next two decades, China can also create an environmental miracle and set a good example for other nations to achieve both socioeconomic and environmental sustainability. The outcome will affect not just China, but the entire world. ■

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