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China's Environment on a Metacoupled Planet

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China, environment, air, biodiversity, climate, water

Abstract

China has emerged as a global economic powerhouse after four decades of unprecedented growth. Such growth has generated many environmental challenges with enormous ecological, socioeconomic, and health consequences in China and beyond. Although the overall quality of air and water is starting to improve, both are still below national and international standards. Water shortages are widespread. Biodiversity continues to decline. China is the world's top CO_2 emitter, although per capita emissions are much lower than those of developed counties. On the positive side, large national conservation programs have been implemented, including the Natural Forest Conservation Program, the Grain-to-Green Program, Ecosystem Functional Conservation Areas, and Ecological Protection Redlines. More than 2,750 nature reserves have been established and a new national park system is being constructed. Some endangered and threatened species, such as the giant panda, are showing signs of recovery, and forest cover and some ecosystem services have increased. These mixed environmental outcomes result from human-nature interactions within China as well as between China and adjacent and distant countries. These include increasing rapid economic growth, resource consumption, land use change, trade and investment, and conservation and development policies. We suggest systems approaches such as nexus approaches and flow-centered governance to help China achieve ecological civilization and become an environmental leader on a metacoupled planet.

Contents

1. INTRODUCTION

China's environmental change is increasingly important for not only China but also the rest of the world. It has significant global implications for the United Nations' Sustainable Development Goals (**http://www.un.org/sustainabledevelopment/sustainable-development-goals**) and other international agreements such as Aichi Targets (**https://www.cbd.int/sp/targets**) and the Paris Climate Agreement (**http://unfccc.int/paris_agreement/items/9485.php**). Many environmental problems have occurred in China amid a rapid population increase and exceptional economic growth over the past four decades (**Figure 1**). Since the Chinese economic reform in 1978, there have been increasing demands for consumption, shifts from a grain-based diet to a more meat-based diet (1), and rapid urbanization (2). Their impacts go far beyond the environment since they also have direct effects on human health and well-being (3). Future impacts have high uncertainty under climate change, globalization, and deglobalization.

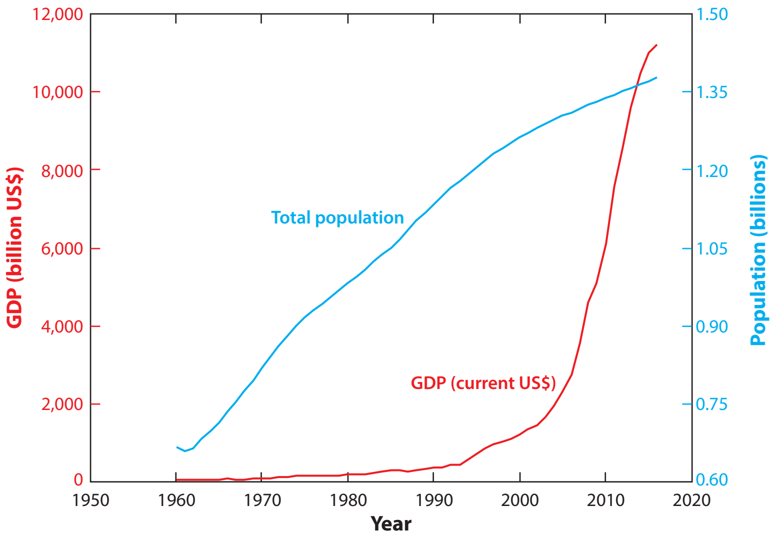

Figure 1

Temporal patterns of total population and gross domestic product (GDP) in China. Data are from the World Bank (**https://data.worldbank.org/indicator**).

China's scientific community, leadership, and the public have realized the importance of environmental protection and sustainable development (4). The government has implemented a series of large-scale conservation policies (5) and has proposed an ecological civilization to harmonize human-nature relationships (6). Hopeful signs have emerged with the increase in forest cover (7), recovery of some endangered and threatened species such as the giant panda (8; see also **http://www.iucnredlist.org/details/712/0**), and improvement in some ecosystem services (9).

The literature related to China's environment is extensive but largely fragmented and scattered. Most papers on China's environment focus on individual aspects of the environment (e.g., air or water). Some review papers have covered multiple aspects of the environment (e.g., air, water, and biodiversity), but they are largely outdated (e.g., 10, 11). Given the rapid changes in China's environment and its complex relationships with human-nature interactions inside and outside China, an updated review under an integrated framework is warranted.

This review places China's environment under the new integrated framework of metacoupling (12), which considers human-nature interactions inside a focal system of interest, between the focal and adjacent systems, and between the focal and distant systems. In this article, the focal system is China, and adjacent and distant systems are countries that are adjacent to, and distant from, China. The metacoupling framework can help examine China's environmental issues more systematically than previous analyses. In the first four sections below, we adopt the metacoupling framework by focusing on four main environmental aspects (air quality, biodiversity, climate change, and water quantity and quality) in relation to human-nature interactions within China. Each section underscores environmental dynamics (changes in each particular environmental aspect), their socioeconomic and environmental effects, causes (or driving forces) behind environmental dynamics, and flows (e.g., movement of matter, energy, information, people, or organisms) related to environmental dynamics. We then illustrate main interactions between China and the rest of the world because such interactions affect not only China's environment but also global sustainability. Finally, we offer policy recommendations to transform China's environmental protection.

2. AIR QUALITY

2.1. Dynamics

Air pollution in China is widely known and has drawn concerns both at home and abroad. In 2017, most cities (71%) did not meet the government's air quality standards (13). In 2015, Chinese cities had an average air pollution ratio (percentage of days with air pollution) of 23% and the highest ratios over 80% (14). Northern China had a higher ratio than southern China (14), and winter had the highest levels of air pollution, whereas summer had the lowest (14).

China has low air quality that had been getting worse until recently. China's air problem is more severe than the world average. For instance, the concentration of particulate matter with a diameter less than 2.5 µm ($PM_{2.5}$) in China's air is higher than the world average (**Figure 2**). In the past few years, air quality has been improving, in some cases dramatically. $PM_{2.5}$ increased 33.3% across 285 Chinese cities during 2001–2012, but decreased 12.3% between 2013 and 2015 (15). The concentrations of $PM_{2.5}$ in large cities were higher than those in small- and medium-sized cities. Data from a ground monitoring network indicate that in 2015 the highest concentrations were located mainly in the North China Plain (Beijing, Tianjin, Hebei, Henan, and Shandong) (16), and the highest and lowest monthly mean $PM_{2.5}$ concentrations were in January and August, respectively (15). According to the Ministry of Ecology and Environment (17), in 2017 the average PM_{10} concentration in 338 large cities declined by 22.7% from the 2013 level, and $PM_{2.5}$ concentrations in the three regions with the most severe air pollution (Beijing-Tianjin-Hebei region, Yangtze River Delta, and Pearl River Delta; see **Figure 3**) dropped 39.6%, 34.3%, and 27.7%, respectively.

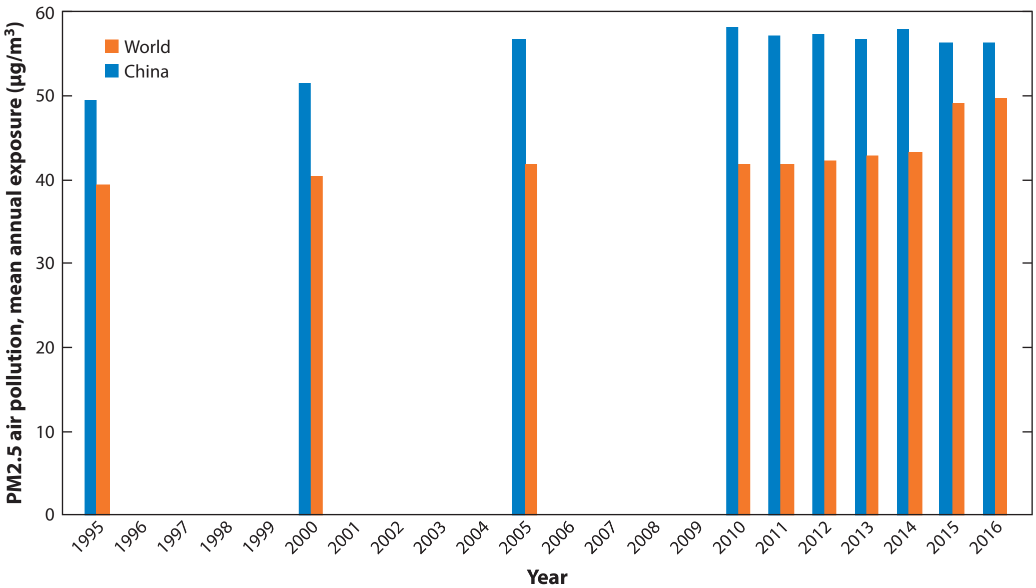

Figure 2

Dynamics of $PM_{2.5}$ air pollution, mean annual exposure in China's air versus the world average. Data are from the World Bank (**https://data.worldbank.org/indicator**).

Figure 3

Map of China showing distribution of the Natural Forest Conservation Program (NFCP) and Grain to Green Program (GTGP); names of provinces, autonomous regions, municipalities; two major rivers; and two major deltas. Figure modified from Reference 5. Copyright 2008, National Academy of Sciences, U.S.A.

2.2. Effects

Air pollution has a wide range of socioeconomic consequences. An increase of 5 μg/m^3 in $PM_{2.5}$ was associated with a reduction in gross domestic product (GDP) of approximately 2,500 yuan per capita as of 2015 (1 US dollar = 6.64 yuan as of July 6, 2018) (18). Due to heavy pollution and subsequent poor visibility, many flights were delayed or cancelled (19), and schools, businesses, and government offices were closed (20). Government agencies frequently issued warnings of severe air pollution (21) and established bans on the operation of vehicles that emit pollutants, and residents were asked to spend less time outdoors (22, 23). Before 2013, air-related complaints were largely local and scattered. However, the highly polluted days in January of 2013 in Beijing and many other cities around the nation prompted a widespread outcry, which also sparked growing media attention and public interest nationwide and worldwide.

$PM_{2.5}$ is associated with many health problems such as cardiovascular and respiratory diseases and increased mortality (24). Short-term exposures to an increase of 10 μg/m^3 in $PM_{2.5}$ concentrations boosted acute myocardial infarction (heart attack) by 0.42%, coronary heart disease by 0.17%, stroke and all-cause mortality by 0.13%, and cardiovascular disease by 0.12% (25). Premature mortality related to $PM_{2.5}$ in China's 161 cities accounted for 652,000 or 6.92% of the total deaths in 2015. Cerebrovascular disease, ischemic heart disease, chronic obstructive pulmonary disease, lung cancer, and acute lower respiratory infections contributed 51.7%, 26.3%, 11.8%, 9.4%, and 0.8%, respectively, to those premature deaths. This premature mortality is particularly high in densely populated cities such as Chongqing (23,561/year), Beijing (18,817/year), and Shanghai (18,679/ year) (26). According to the World Health Organization (WHO), of the three million premature deaths worldwide in 2012, more than one million were in China (27). Another study suggests that average life expectancies are approximately 5.5 years shorter in northern China due to an elevated incidence of cardiorespiratory mortality caused by total suspended air pollution (28). Furthermore, 3.7 billion life years could be saved if all of China complies with its Class I standards for PM_{10} (29).

Air pollutants also have a variety of impacts on plants, animals, and natural ecosystems. Sulfur dioxide directly affects plants through phytotoxic and acidifying effects, and nitric oxide has both direct and indirect influences on plants by penetrating through the stomata and through soil acidification (30). *Sophora japonica* L., a native tree species occurring widely in many regions of China, is affected by traffic pollution through significant accumulation of heavy metals (e.g., Zn, Cd, Hg, Pb, and Cr) in roadside leaves and soils (31). Atmospheric deposition most likely led to heavy metals and persistent organic pollutants in the tissue of bamboo species—which are the main diets of iconic wildlife such as the giant panda in the Shaanxi Province of north China (32).

2.3. Causes

China's air pollution is caused by a variety of factors. It is positively associated with factors such as population density, GDP, coal-dominated energy structure, the proportion of secondary industry, and vehicular traffic density (14, 15). While air pollutants come from various sources (15, 33), an important source is the transportation sector. Automobiles and roads have increased exponentially in the past several decades. China has promoted automobile production as one of its key industries. From 1978 to 2015, China's private vehicle fleet increased from 1.36 to 162.84 million (34). As early as January 2009, more cars were purchased in China than in the United States. Since then, China has continued to boost automobile production and consumption. Even with government control of automobile quotas (through a lottery system), the enthusiasm to purchase private vehicles continues (35). China still has great potential to increase private automobile ownership, with only 83 automobiles/1,000 persons, much lower than that (797 automobiles/1,000 persons) in the United States in 2014 (**http://www.nationmaster.com/country-info/stats/Transport/Road/Motor-vehicles-per-1000-people**).

China's central government has demonstrated a growing determination to address air pollution since the acute period of bad air quality over Beijing and much of the country in January 2013. In February 2014, President Xi Jinping declared "war" on air pollution. The State Council has issued a series of action plans to reduce $PM_{2.5}$ concentrations by 15–33% in the most affected regions relative to 2012 (36, 37). To achieve such a goal, these plans call for reducing energy intensity by 20% and limiting coal use to 65% of all primary energy. Furthermore, the plans established specific measures for limiting emissions through requiring a shift to larger-scale facilities, installing pollution control equipment, phasing out outdated and substandard furnaces, and relocating polluting enterprises. Huge amounts of funding have been allocated to implement these plans. For example, the estimated cost of the action plans alone exceeded 1.7 trillion yuan during 2013–2017 (38). For successful implementation, the central government would hold senior provincial officials accountable for meeting the targets, using a scoring system to evaluate local government performance (37). Enactment of these plans has already exhibited positive outcomes, as demonstrated by a simulation study showing that $PM_{2.5}$ concentrations decreased from 2013 to 2015 (36, 39). However, more research is needed to rigorously evaluate the overall effectiveness and consequences of various policies (15).

2.4. Flows

Many air pollutants move among places due to natural air circulations, trade of goods, and industrial transfers (15). As a result, air pollution in one place is closely associated with other places, especially neighboring cities and provinces. There is a difference between the physical flow of air pollution across space versus the trade in goods. For the embedded air pollution in traded goods, damage occurs in places where the goods were produced (or downwind).

Emissions of air pollutants embodied in trade of goods can cross a region or the entire country. At the regional level, for example, in the Beijing-Tianjin-Hebei urban agglomeration (northern China), the net transferred embodied emissions of four major air pollutants (NO_x, SO_2, soot, and dust) from Hebei province to Beijing in 2015 were 31.9, 25.2, 23.3, and 15.0 kt, respectively. Hebei also provided net transferred embodied emissions of NO_x, SO_2, soot, and dust to Tianjin in the amounts of 11.9, 9.4, 9.3, and 6.5 kt, respectively. Tianjin exported these pollutants to Beijing in the net amounts of 3.7, 2.8, 1.7, and 0.2 kt, respectively (40).

Across the nation, emissions embodied in trade between provinces are primarily driven by domestic supply chains from production in less developed interior provinces to consumption in more developed coastal regions. For instance, more than 60% of the consumption-based SO_2 emissions in Beijing, Tianjin, the Yangtze River Delta, and the Pearl River Delta in 2007 were produced in other provinces (41). Interior provinces with lower per capita GDP and lower technology levels than coastal regions had higher emission intensities and generated almost 75% of the interprovincial trade-related emissions. For example, the SO_2 emission intensity of interprovincial exports in Guizhou province was 6.6 times that of imports from other provinces. The coal-fired electric power industry in Inner Mongolia generated twice the amount of SO_2 per US$ of electricity than that in Shanghai (41).

3. BIODIVERSITY

3.1. Dynamics

China is one of the world's 17 "mega-diversity" countries (42), ranking third after Brazil and Colombia in the total number of species (43). It has the richest assemblage of biodiversity in the temperate Northern Hemisphere, with more than 9% of terrestrial vertebrate species and vascular plants worldwide. For instance, China has approximately 33,000 vascular plant species in more than 3,000 genera, with approximately 334 families of angiosperms, 42 genera and 11 families of gymnosperms, 231 genera and 63 families of pteridophytes, and 500 genera and 106 families of bryophytes (44). China also ranks high in its number of endemic species, as it has more than 10,000 endemic higher plant species, and approximately 243 genera that only occur within its borders (45). The 2017 Catalogue of Life records 80,390 species and 11,911 infraspecific taxa (46).

Some high-profile species have been recovering, including the giant panda (8, 47), the crested ibis (48), and the Tibetan antelope (49). In fact, the pandas have been downgraded from endangered to threatened (**http://www.iucnredlist.org/details/712/0**). However, the habitat and population sizes of many other high-profile species such as the Chinese sturgeon (50) and the South China tiger (51) have continued to drop, and some species such as the Yangtze River dolphin may have become extinct (52).

The latest red list of China's biodiversity indicates that more than 10% of higher plants (53) and more than 20% of vertebrates (54) are threatened or have gone extinct. Furthermore, despite the enactment of policies to protect and restore wetlands (55), 79% are in poor conditions (56). Noncharismatic species that do not receive media attention get little protection unless they are in the same areas of charismatic species like the giant panda (57). For example, many bee species are at risk despite China being the world's major honey producer, with more than eight million managed bee colonies (58).

3.2. Effects

Biodiversity is essential to ecosystem services—benefits that ecosystems provide to people. In China, this is particularly important because approximately half of the population lives in rural areas and directly depends on ecosystem services such as food production, biological control, herbal medicine, soil retention, water retention, flood mitigation, and sandstorm prevention. The urban population also relies on these ecosystem services, although indirectly. For instance, biodiversity is important to crop production. The wild relatives of currently domesticated crops provide the genetic diversity needed to develop crop varieties that may be more productive, nutritious and resilient to pests (59). Higher biodiversity has also been reported to reduce the effects of pollutants in terrestrial and aquatic systems (60, 61), for example, reducing by approximately 50% the amount of nutrients that cause eutrophication through the increase in diversity and areal coverage of aquatic macrophytes. In addition, a high diversity of pollinators increases crop yields by approximately 12% (62). Furthermore, ecosystem services such as carbon sequestration through reforestation have global climate implications (7, 63).

Biodiversity also has significant effects on ecosystem structure and functioning. For example, increases in tree species diversity is associated with an increase of approximately 18% in the amount of leaf litter, and a reduction of approximately 21% in the carbon-to-nitrogen ratio in the litter of subtropical forests (64). Also, although higher tree species richness was associated with 50% higher levels of leaf damage due to herbivorous insects, this occurrs mostly under a low phylogenetic diversity of herbivores (65), suggesting that higher insect diversity may reduce leaf damage. Furthermore, total leaf area index and fine-root biomass (associated with higher standing biomass and productivity) increases by 66% (66) and 10% (67), respectively. Whereas most studies have focused on individual functions and taxonomic groups, high biodiversity is directly related with higher levels of multiple function in both aquatic and terrestrial ecosystems (68). Thus, the loss of biodiversity in China is associated with the loss of multiple ecosystem functions with negative consequences that cascade across space and time, and ultimately impact human systems (e.g., through disruptions in the supply of timber, food, water, fiber, and other goods and services) not only in China but around the world.

3.3. Causes

China's biodiversity dynamics are influenced by a variety of factors. They range from land use/cover change (69), hunting (70), collection of herbal medicine (71), pollution (72), mining (73), plantation (74), damming (75), invasive species (76), fires (77), wetland drainage (78), disease (79), and policies (80), to natural disasters such as earthquakes (81). The importance of these factors varies across space, over time, and among different taxa. For instance, threatened plant species in China tend to be concentrated where anthropogenic activities have recently intensified (82), which points to the drastic effect of human activities on biodiversity.

In the past several decades, China experienced rapid and drastic land use/cover change (83). A substantial amount of natural land cover (e.g., natural forests, grasslands, and wetlands) has been converted for residential and industrial development, roads, croplands, highways, railroads, and airports. For example, from the late 1980s to 2010, 21,227 km^2 of forests and 54,314 km^2 of grasslands were converted to croplands (84). This has led to enormous habitat loss and fragmentation, which is among the most important causes of biodiversity loss (85).

To reduce the negative impacts of human activities, the Chinese government has been implementing a series of ecological conservation programs such as logging bans, regulations for conservation of wild flora, wildlife conservation and nature protection programs, grassland ecological

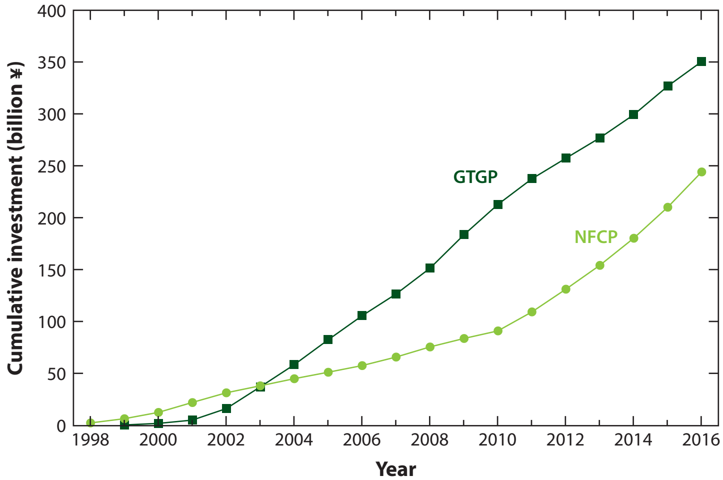

Figure 4

Cumulative amounts of investment in the Natural Forest Conservation Program (NFCP; 1998–2016) and Grain to Green Program (GTGP; 1999–2016). Data are from Reference 208.

conservation programs, wetland conservation and restoration plans, and payment for ecosystem service programs (7, 55, 86, 87). They include two of the largest ecological conservation programs in the world since the late 1990s and early 2000s: (*a*) the Natural Forest Conservation Program (NFCP), which bans logging in natural forests, and (*b*) the Grain-to-Green Program (GTGP), which encourages farmers to return cropland on steep slopes to forests or grasslands by providing cash, grain, and tree seedlings (5). These programs are nationwide (**Figure 3**) and have received large amounts of investments (**Figure 4**). These and other programs have helped increase many ecosystem services nationwide, although there were still areas of ecosystem service degradation (7, 9). These programs have been producing overall positive effects on forests not only at regional (5) but also at national (7) scales. However, many of the reforested areas often consist of fast-growing exotic species that diminish their biodiversity value (88). In 2016, the Chinese government also amended the Wildlife Conservation Law to improve the effectiveness of wildlife conservation.

China has built a large nature reserve system to protect biodiversity. By the end of 2017, 2,750 nature reserves were established, covering approximately 15% of the land area (13, 80, 89) (**Figure 5**), which is higher than the world average. However, there is generally low congruence of areas rich in endemic biodiversity (much in eastern China) and nature reserves (located mostly in western China), and covering a relatively higher percentage of habitat area for threatened mammals and birds than for plants, amphibians, and reptiles (80). Furthermore, some reserves do not have sufficient funding for effective management and are negatively affected by development and urbanization (89). Rezoning nature reserves for economic development (e.g., road construction, mining, construction of hydropower plants, and tourism) has reduced the total area even as the total number has increased (**Figure 5**).

Biodiversity also benefits—from the enactment of other policies. China announced the policy of Ecosystem Function Conservation Areas in 2008 and later made a revision in 2015 (90). The policy of Ecosystem Function Conservation Areas is a national land zoning plan, which identifies different types, patterns, problems, sensitivities, functions, and key services of China's ecosystems. It plays a crucial role in defining regions that are important to national or regional ecological security in a spatially explicit manner. It also sets a benchmark that other national, regional,

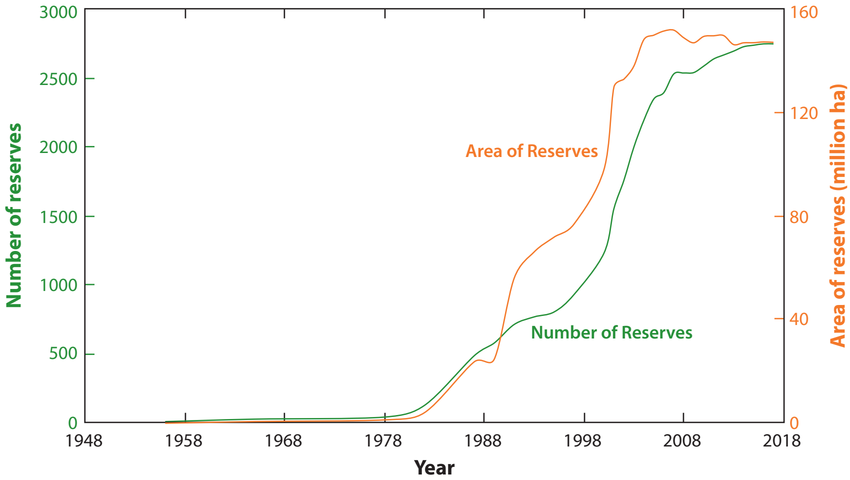

Figure 5

Growth of China's nature reserves. Data are from References 13, 209, and 210.

and local policies should follow. There are 63 such areas, accounting for 49.4% of China's total land area (90). A series of measures have been proposed for the conservation of these areas, such as pollution control, grazing limits, reduced mining and road construction, and promoting the recovery of natural vegetation (90). Under the guidance of Ecosystem Function Conservation Areas, China designed another national policy, the Ecological Protection Redlines (91), which refers to areas that have important and special ecological functions and must be strictly protected, as they are fragile, ecologically sensitive, or constitute an essential "lifeline" to safeguard and maintain the national ecological security. By 2020, approximately 25% of China's territory will be included in the Ecological Protection Redlines (92). Finally, the emerging national park system may provide additional means for biodiversity conservation as it is expected to be a key component of nature conservation and to play an important role in protecting representative ecosystems and natural landscapes (93).

3.4. Flows

Animals and plants move among different regions of China through dispersal and migration, which support the structure and function of biodiversity and ecosystems. This is particularly important for long-term survival of endangered or rare animal (94) and plant (95) species. Such functional connections are also particularly crucial for the current and future success of protected areas in meeting their conservation goals (96). However, landscape connectivity across China is being negatively affected by human activities, particularly the unprecedented development of extensive road networks. Over the past decade, China's road network has increased fourfold (97) and is negatively affecting the connectivity and movement of many species, including endangered ones (47). Migratory species need to spend time in different habitats. For example, approximately 500 migratory bird species depend on coastal habitat, which has undergone rapid destruction due to the construction of sea walls, land reclamation, and other forms of economic development (98). Between 2000 and 2010, China's total length of natural coastal lines decreased by 14.1% (1,253.3 km), while the total length of constructed coastal lines increased by 30.0% (2,300.9 km) (9). To address this problem, China has recently introduced a tough regulation on land reclamation along its coastline (99). If this regulation is fully implemented, very few reclamation projects will be approved, and illegally reclaimed land will be demolished (99), thus benefitting migratory species in particular and biodiversity in general.

The trade of plant and animal species also contributes to biodiversity dynamics in China (100). Zoos and botanic gardens routinely obtain wildlife and plant species from other regions for education, exhibitions, breeding, and research. For example, 22 cities across China hosted at least one giant panda from Wolong Nature Reserve in Sichuan Province as of 2010 (101). However, there is also widespread illegal trade of wildlife and plants for food, traditional Chinese medicine, and ornamentation despite many government regulations (102). Such illegal trade has led to the dramatic reduction in the populations of many plant and animal species, some becoming endangered (103, 104).

4. CLIMATE CHANGE

4.1. Dynamics

In China, a warming trend has been observed over the past 50 years, with temperature increases of 0.2–0.3°C and approximately 0.1°C per decade in northern and southern China, respectively (105). Since 1990, temperature anomalies over the base period from 1951 to 1980 have been positive and increasing in magnitude across the entire country. China has experienced increasingly uneven precipitation patterns between the more humid southern and the drier northern portions of the country, together with an increase in the incidence of extreme events, including the huge flood of 1998 and severe drought of 2010–2011 (106, 107). Furthermore, the majority of glaciers located in the Tibetan Plateau are retreating and thinning due to the trend of increasing temperature associated with global climate change (108). Areal reductions of approximately 37% between 1989 and 2014 have been reported, with rates of reduction of 1.5% per year (109). Sea level has risen 0.1–0.25 cm/year (110).

4.2. Effects

Climate change in China has a series of impacts on human and natural systems. Glacier thinning is causing an increase in water discharges to glacier-fed lakes and rivers, increasing their water levels. Such discharges have resulted in an expansion in the area of glacier-fed lakes of approximately 122% between 1976 and 2010, whereas lakes not connected with glaciers have remained stable (111).

Climate change has significant effects on the biota. More than 90% of the species of trees, shrubs, herbs, birds, amphibians, and insects have already shown earlier onsets of spring/summer phenophases, and 69% have exhibited later onsets of autumn phenophases (112). Under the most extreme climate change scenarios, approximately 70% of woody species are expected to lose more than 30% of their current geographic range (113), while approximately 6% of woody species may become extinct (113). Changes in temperature and precipitation regimes may ease different climate constraints on plant growth, which translates into increases in net primary productivity (NPP), but extreme events, including droughts and floods, reduce NPP (114). Over the past 50 years, the NPP dynamics of grassland ecosystems in northern China and in the Tibetan Plateau have been negatively influenced by warming trends and reduced precipitation (115).

Climate change has substantial socioeconomic consequences such as impacts on food security. With increases in temperature over the past 50 years, the farming-pastoral ecotone has exhibited an overall shift toward northern latitudes (116), which contributed to a 2.2% increase in China's production of the three most important cereal crops (maize, wheat, and rice) from 1981 to 2010 (117). However, increased temperatures also tend to shorten the period of crop growth, with some regions experiencing drastic yield reductions (95, 107, 117), particularly the northeastern region of China where a warmer climate speeds up crop development and generates short growth periods, and thus reduced yields (118). The reduction in crop yields due to the warming trend has caused direct economic losses to China's maize and soybean production over the past decade (estimated to be approximately US$820 million), with further projected declines in maize and soybean yields of 3–12% and 7–19%, respectively, by 2100 (107). Furthermore, given that China has become the world's largest consumer of maize and soybeans, these negative climate change effects are passed to the global food market through trade, affecting food security worldwide (119).

Climate change also exerts significant impacts on human health and conflicts. For instance, the transmission rate of climate-sensitive diseases will likely increase under current and projected trends of climate change (120). Substantial net increases in human population exposed to malaria vectors are projected, with rates as high as 20% and 40% by the 2030s and 2050s, respectively (121). A warming climate is also significantly related to an increase in heat-related mortality rates, particularly in urban areas of the north, east, and central regions of China (122). Such urban areas are projected to exhibit annual increases of 2.3% in their excess mortality rates by 2070 (122). Non-urban areas are expected to have even higher rates, with higher percentages of older people, lower prevalence of air conditioning, and insufficient hospital infrastructure (123). There have been significant positive relationships between violent and property crimes and climate variables such as temperature and relative humidity (124).

4.3. Causes

Climate change mainly results from the accumulation of approximately 16 types of greenhouse gases, including CO_2. China has been leading the world's CO_2 emissions since 2006 (**http://factsanddetails.com/china/cat10/sub66/item393.html**; see also **Figure 6**). For instance, in 2012, China's CO_2 emissions from fuel combustion accounted for 25.9% of global emissions (125), and more than half of the increase in CO_2 emissions worldwide between 1990 and 2012

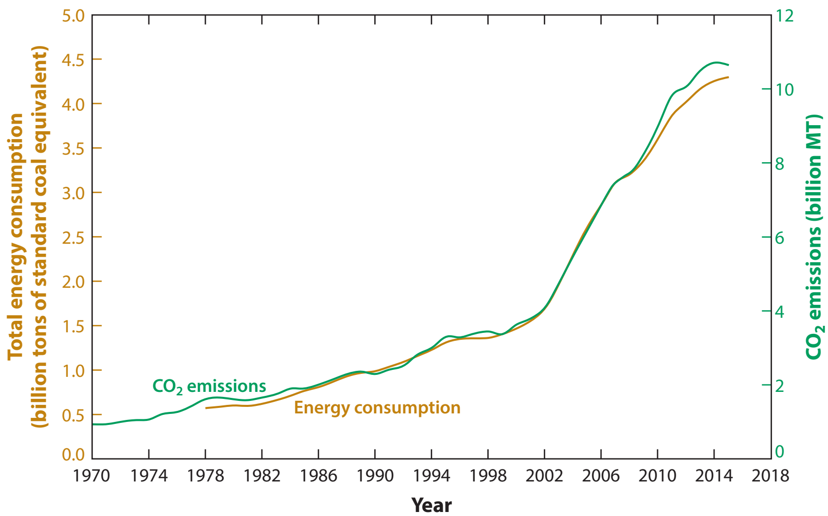

Figure 6

Energy consumption and CO_2 emissions in China. Data are from References 34 and the following: **http://edgar.jrc.ec.europa.eu/overview.php?v=CO2ts1990–2015**.

was linked to China (125, 126). However, per capita CO_2 emissions in China were only 42% of the US levels as of 2015 (**https://www.ucsusa.org/global-warming/science-and-impacts/science/each-countrys-share-of-co2.html#.Wpmj3q6nHDB**).

A major source of CO_2 emissions is energy consumption. Rapid economic growth has elevated China to the world's largest energy consumer since 2009 (see **https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html**; see also **Figure 6**), with its total consumption level having increased more than 630% since 1980. As the world's largest producer and consumer of coal, coal is still China's principal energy source, although it has dropped from generating more than 90% of China's total energy in the 1950s to 62% in 2016 (**https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html**). In addition, China has become the second largest consumer of petroleum (**https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html**).

The Chinese government has started implementing a series of measures to counter climate change. For instance, in 2007 China established a National Leading Group on Climate Change and became the first developing nation to call for an increase in nonfossil fuels to 15% of primary energy by 2020 (82). As promised to the United Nations Conference of Parties in 2009, the State Council planned to cut carbon intensity by 40–45% by 2020 from the 2005 level. The 12th Five-Year Plan (for 2011–2015) called for reducing energy intensity by 16% and reducing overall CO_2 emissions by 17%. The 13th Five-Year Plan (2016–2020) aims to limit total energy consumption below 5 billion tons of standard coal equivalent (127). China also aims to further reduce CO_2 emissions per unit of GDP by 60–65% from the 2005 levels, and in 2016 this measure exhibited reductions of 6.6%, exceeding the expected 3.9% goal (**http://www.xinhuanet.com/english/2017-12/19/c_136838026.htm**). China is the first developing nation to control CO_2 emissions through a cap-and-trade system that sets a cap or limit for CO_2 emissions by an institution (e.g., company), but allows the institution to go beyond this limit through buying allowances from other institutions. This system provides a solid foundation for establishing a national carbon market that is anticipated to overtake the European Union as the world's largest carbon market (**http://www.xinhuanet.com/english/2017-12/19/c_136838026.htm**).

As a natural force to counter CO_2 emissions, China's vegetation plays important roles in sequestering CO_2. Percent forest cover has increased since the 1960s (**Figure 7**). Between 1950 and 2010, China's plantation forests alone sequestered 1.69 Pg C through net uptake into biomass and emissions of soil organic carbon (128). The carbon sink between 2001 and 2010 in the region of six ecological restoration projects was 132 Tg C/year, 56% of which (74 Tg C/year) was attributed to the implementation of these projects (129). An analysis of the literature from 2004 to 2014 indicates that carbon densities of vegetation and soils (0–100 cm) in China's forest ecosystems were approximately 69.2 Mg C/ha and 116.5 Mg C/ha, respectively (130). From 1982 to 2011, the total carbon storage of grassland ecosystems in China was approximately 31.2 Pg C, with 96% stored in the soil (131). During 2001–2010, the total C stock of terrestrial ecosystems was 79.24 Pg C, with 38.9%, 32.1%, 20.6%, and 8.4%, in forests, grasslands, croplands, and shrublands, respectively (132). However, the magnitude of China's C sequestration relative to emissions is small. For instance, from 2001 to 2010, the elevated C stocks are equivalent to only 14.1% of the C emissions from consumption of fossil fuel (132).

4.4. Flows

Within China, many goods are consumed outside the regions where they are produced. Such spatial separation generates large amounts of greenhouse gas emissions in the embodied goods. A study

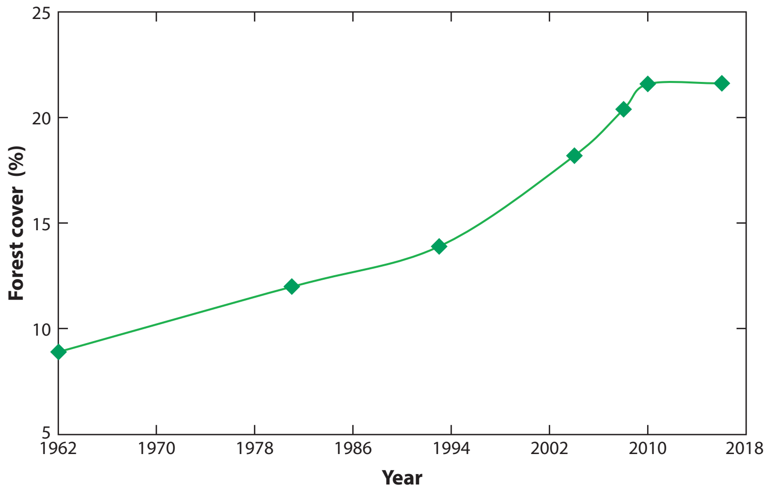

Figure 7

Dynamics of China's forest cover. Data are from References 34 and 172.

reports that more than half (57%) of China's CO_2 emissions are attributed to the goods traded across regional boundaries (126). As much as 80% of the emissions related to goods consumed in the developed provinces in eastern China come from less developed provinces in central and western China (126).

Understanding flows across regions shed insights not only on the contributions of various regions to total domestic CO_2 emissions as illustrated above, but also on contributions of various regions to CO_2 emissions as a result of international trade. Approximately 74% of China's exports in 2007 came from the central and southern coastal regions (133). However, 40% of the emissions related to exports from coastal regions actually originated in other regions of China (126). For instance, embodied CO_2 emissions in exports from the central coastal region included emissions in the central (77 Mt), north (70 Mt), and northwest (38 Mt) regions of China (126).

5. WATER QUANTITY AND QUALITY

5.1. Dynamics

China's freshwater resources are in severe short supply and are largely polluted. Average per capita freshwater in China is only one-quarter of the world's average. Two-thirds of China's 669 cities and many food production areas face water shortages, a problem that is exacerbated by pollution.

In terms of water quantity, among the 4,049 reservoirs surveyed, the total water storage at the end of 2016 was 395.4 billion m^3, 4.1 billion m^3 less than at the beginning of the year. In the 29 lakes with at least 100 km^2 each, however, there was a total of 130.1 billion m^3 at the end of 2016, 1.1 billion m^3 more than at the beginning of the year (134).

A national survey of rivers (total length of 235,000 km in 2016) indicates that rivers with good or slightly or moderately polluted water accounted for 76.9% (an increase of 3.5% from the 2015 level), whereas heavily polluted rivers accounted for 9.8% (a decrease of 1.7% from the 2015 level) (134). Monitoring data from 1998–2015 also suggest that the proportion of heavily polluted rivers has been decreasing (**Figure 8*a***). Data from 118 lakes in 2016 with a total of 31,000 km^2 water surface show that there were 28 lakes with good or slightly polluted water (a decrease of 0.9%

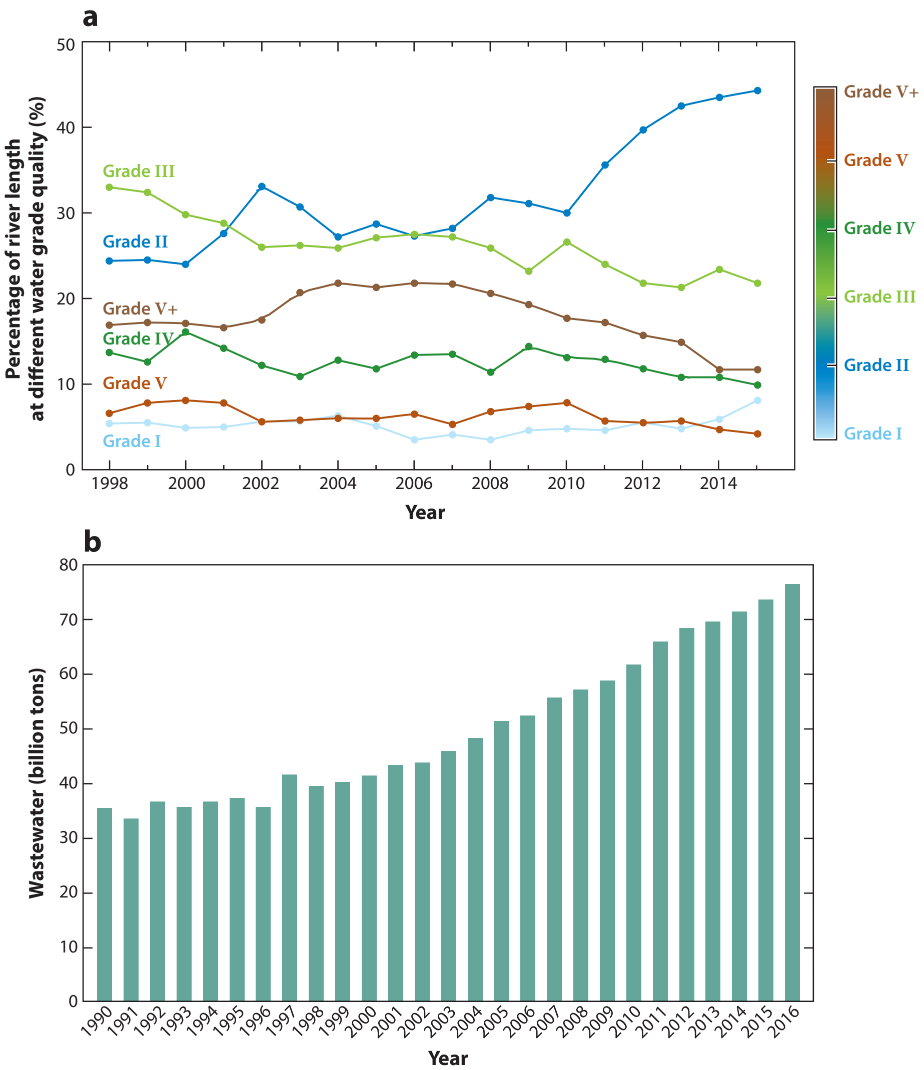

Figure 8

(*a*) Changes in percentages of China's river length under different grades of water quality. Data for the panel are from References 134 and 145. Unpolluted or slightly/moderately polluted (Grades I–III), polluted (Grade IV), and heavily polluted (Grades V and V+) water qualities are shown. In terms of utilities, Grade V+ is not suitable for any use, whereas Grades II-V can be used for restricted purposes (e.g., rare and valuable aquatic species, swimming and aqua farming, industrial and recreational activities that do not include direct contact with human bodies, and agricultural uses and landscape design, respectively). (*b*) Annual amount of wastewater released in China. Data for the panel are from References 11, 134, 145, and 211.

from the 2015 level), 69 with pollution, and 21 with heavy pollution. Among the 943 reservoirs in 2016, reservoirs with good or slightly polluted water, polluted water, and heavily polluted water accounted for 87.5%, 9.3%, and 3.2%, respectively. Reservoirs with good or slightly polluted water in 2016 increased by 4.3% from 2015. The main pollutants in the water included ammonia nitrogen, total phosphorus, and chemical oxygen demand. Among the 867 main drinking water sources in 2016, 693 reached the quality standard at least 80% of the time throughout the year, 1.4% more than those in 2015 (134).

5.2. Effects

Water pollution and shortages have a wide range of impacts on aquatic ecosystems, socioeconomic conditions, and human health. Some rivers, lakes, and wetlands have dried up, causing the disappearance of their associated animals and plants (135). Among the remaining rivers and lakes, many are shrinking or are polluted (135). For instance, all 45 key lakes monitored across China in 2014 suffered from eutrophication (136). Water pollution, such as high nitrogen loading, inhibits the growth of aquatic plants (137).

Water shortages affect human livelihoods. Approximately 300 million rural residents lack access to safe drinking water. Approximately 900 million people in China (out of 4 billion people globally) live under severe water scarcity at least one month of the year (138). There is widespread competition and conflict over water between downstream and upstream communities, among different sectors such as agriculture and industrial factories, and among different regions. More cities and agricultural regions have been exploiting underground aquifers more aggressively, with drilling reaching depths of several thousand meters. For example, in the North China Plain that contributes to approximately 40% of China's agricultural production, the groundwater level is falling rapidly and is now hundreds of meters below ground in some areas (11). With a rapid drop in groundwater levels, more than half of China's provinces have been experiencing surface subsidence (139, 140).

Water shortages and pollution produce food and health risks. Approximately 12% of China's river water is too polluted for any use, even for irrigation (**Figure 8*a***). However, water shortages force the use of polluted water for irrigation. This has led to the increase in the concentration of heavy metals and other pollutants in food (141), placing the health of numerous people at risk (141) and exacerbating food safety concerns over widespread applications of agrochemicals such as fertilizers and pesticides.

5.3. Causes

China's water shortages are the result of multiple factors, including high demands due to its large population size, rapid urbanization, and having the fastest growing economy on Earth over the past four decades (**Figure 1**) (142). This is aggravated by an uneven distribution of water resources. China's precipitation ranges from <100 mm to >2,000 mm with higher amounts to the south and east (11), and also differs substantially among years and seasons (143). Low water-use efficiency further contributes to China's water shortages. In terms of GDP per unit of water, it is approximately one-third of the world average. Although efficiency is increasing due to gradual improvements in the industry structure and the economic development model, it may take a long time to reach the world's efficiency level (144).

Water shortages are further exacerbated by pollution. Wastewater discharges from factories and nonpoint agricultural pollutants (e.g., fertilizers and pesticides) have caused severe pollution (e.g., eutrophication) in lakes, rivers, reservoirs, and coastal regions. As **Figure 8*b*** indicates, the amount of wastewater discharged doubled between 1990 and 2016. However, an increasing proportion of wastewater has been treated (145). A large number of projects and factories generating severe pollution and water consumption are situated in areas with high environmental vulnerability. Non-point agricultural pollution is heavy, as China is the world's leading consumer of chemical fertilizers, producer of livestock, and producer and consumer of pesticides (11).

To address water problems, China has developed many policies and made huge investments, particularly to build water infrastructure. For instance, the number of reservoirs in China reached 98,460 by the end of 2016, with a total storage capacity of 897 billion m^3 (146). The water policy instated in 2011 aims to quadruple total investments (to four trillion yuan) over the following 10 years (143). Between 2011 and 2016, a total of 2,644 billion yuan were invested (146). Other policies include Beijing's restriction of immigration while also promoting the relocation of people and organizations to other areas (147, 148). Despite these actions, water shortages remain a big barrier to economic and environmental sustainability (149, 150).

5.4. Flows

Given the uneven supply of, and demand for, water resources, both physical water flows through major water transfer projects and virtual water flows through trading goods are increasingly important in China (151). Analyzing water flows can help us understand water consumption (footprints) and the impact of virtual water flows on water scarcity. In 2007, physical water flows accounted for 4.5% of China's national water supply, whereas virtual water flows amounted to 35% (152). These water flows aggravate water stress in water-sending systems, and do not substantially reduce water scarcity in water-receiving systems (152).

For physical water transfers, China has built numerous water diversion projects since the 1950s, including 12 major ones that divert a total of 108 billion m^3 of water annually (143). These physical water transfers are crucial for areas such as Beijing with severe water shortages (7, 153). Several large diversion projects are being planned, developed, and expanded (143), such as the South-to-North Water Transfer Project—the longest and largest water diversion project in the world, with a planned investment of 486 billion yuan and 45 billion m^3 of water being transferred per year (154).

Virtual water transfers across China are substantial. Inter-provincial flows of virtual blue (surface or ground) and gray (waste or polluted) water were 794.6 and 91.8 Gm^3/year, respectively, contributing to 23.4% of China's water footprints in 2007 (155). Virtual water flows from agriculture accounted for 66.8% of the total virtual water flows. The process of producing water-intensive and high-pollution goods has intensified water scarcity in water-sending systems (155).

6. INTERACTIONS BETWEEN CHINA AND THE REST OF THE WORLD

China's environment is affected by not only human-nature interactions inside China, but also those with adjacent and distant countries (156, 157). Concurrently, China's impacts on neighboring and distant countries have also been growing rapidly (103, 158). Understanding the interrelationships between China and the rest of the world can help international organizations and policymakers around the world to make a joint global effort to address environmental challenges in China and elsewhere.

6.1. Flows

China and other countries have increasing exchanges in many ways, such as international trade (159), investment (160), tourism (161), technology and knowledge transfer (162), cultural exchanges (163), species invasion (76), and movement of water, wildlife, and pollutants (164, 165). Due to space limitations, below we highlight only two globally common exchanges: international

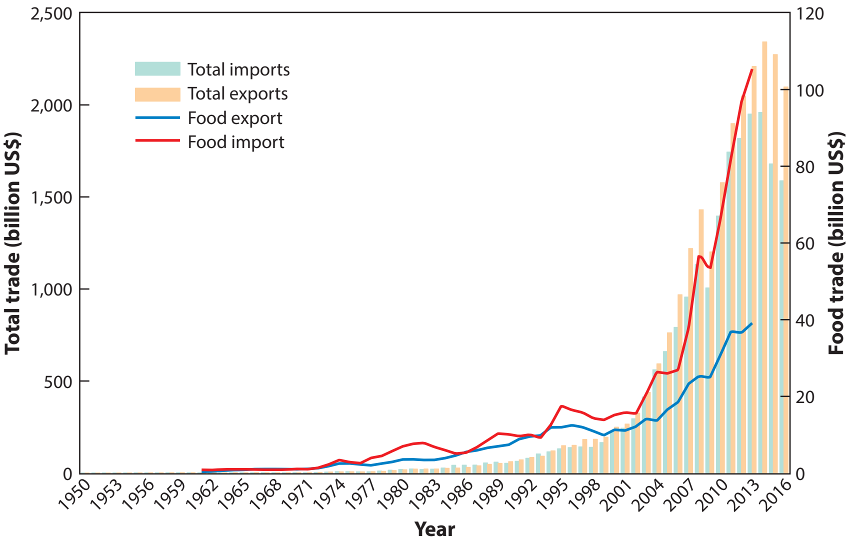

Figure 9

Dynamics of China's total imports and exports (data are from Reference 210) and food imports and exports. Data are from **http://www.fao.org/faostat/en/#data/TP**.

trade, foreign direct investment (FDI), and an exchange that, although comparatively small, has important symbolic and conservation value to China and the rest of the world—panda loans. Although trade between China and other countries remained very low between 1950 and the 1980s, it began to increase gradually until China joined the World Trade Organization in 2001 when trade started to increase exponentially (**Figure 9**). Exports have exceeded imports throughout recent decades. One basic traded product is food. China used to meet its food needs from its own domestic production but now increasingly depends on imports. From 1961 to 2002, food trade between China and other countries was very low and remained approximately balanced. Between 1995 and 2002, there was a small net import. Since 2003, the gap between food imports and exports has been expanding (**Figure 9**).

The trade between China and adjacent versus distant countries varies. For instance, the total amount of fossil fuel trade between China and all adjacent countries is smaller than with all distant countries, whereas the average amount of trade per adjacent country is larger than that per distant country (**Figure 10**). The trade differences between adjacent and distant countries have important implications because trade with distant countries generally takes more time (and thus consumes more energy) to transport goods and products than with adjacent countries.

FDI represents financial capital invested in a country that provides manufacturing and service capabilities for both domestic and world markets. In China, FDI has increased exponentially since the 1980s (**Figure 11**). China overtook the United States in 2000 as the world's largest recipient of FDI due mainly to the sheer size of its market, infrastructure development, availability of labor and natural resources, political stability, and opening up to international markets (166). However, China's overseas direct investment (ODI) has also increased exponentially since 2007 (**Figure 11**), particularly in African countries where surprisingly it has targeted more the services and manufacturing sectors than the natural resources sector (167).

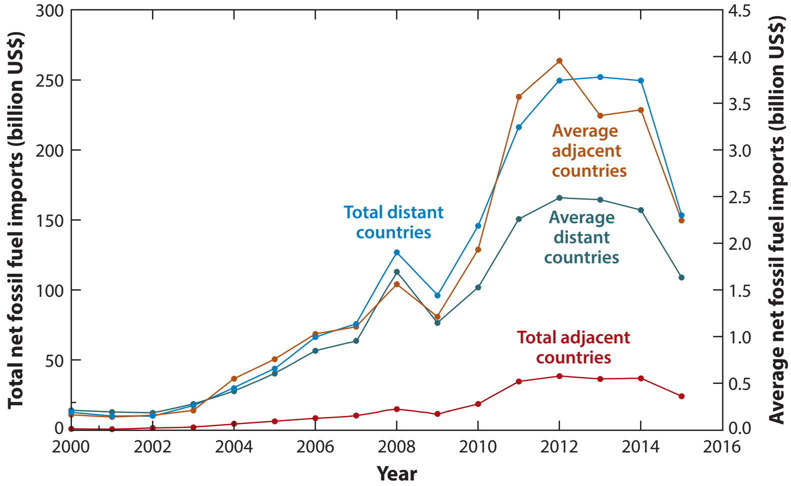

Figure 10

Dynamics of total and average values of fossil fuel trade between China and adjacent or distant countries. Data are from the following: **https://resourcetrade.earth**.

A unique, highly demanded, and increasing flow from China to other countries is panda loans (101). The panda loan program enables zoos in other countries to borrow pandas from the captive breeding center in Wolong Nature Reserve over a period of time (often 10 years) for a fee (up to US$1 million/panda/year). The breeding center has the world's largest number of captive pandas (more than 200; see Reference 101). The number of pandas from Wolong Nature Reserve to other countries jumped from 2 in 1998 to 24 in 2010. Although the direct economic value of panda loans

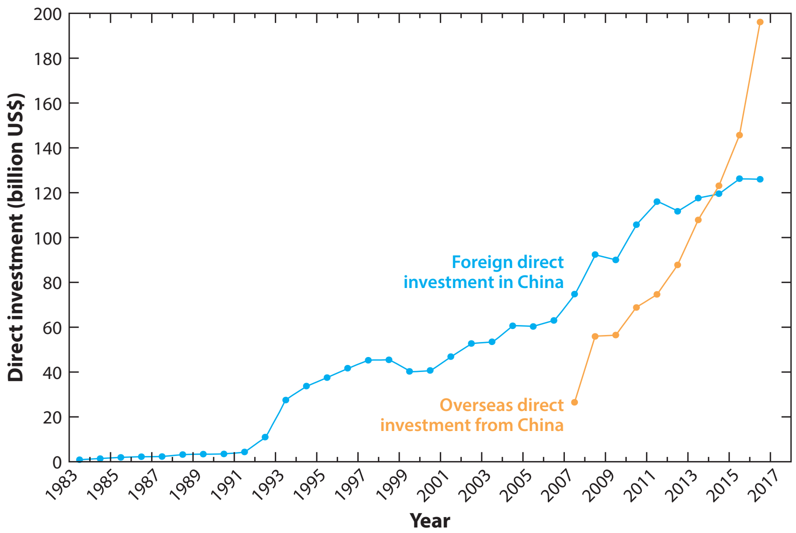

Figure 11

Dynamics of foreign direct investment utilized by China and China's overseas direct investment in other countries. Data are from Reference 145.

is small compared to that from other business deals, they represent direct biodiversity connections between China and other countries, and help seal other business deals. For example, the loan of pandas to the Edinburgh Zoo in 2011 was part of business deals of £2.6 billion (US$3.94 billion), such as China obtaining rights to oil from a Scottish oil refinery and dramatically increasing imports of fisheries (101).

6.2. Effects

As the fastest growing driver of global carbon emissions, international trade is associated with large quantities of emissions embodied in Chinese exports (168), larger than the annual emissions of top exporters such as Japan or Germany. Many studies have pointed out international exports as an important cause of Chinese CO_2 emissions (169, 170). For example, the proportions of CO_2 emissions due to production for exports increased from 12% (230 Mt) in 1987, 21% (760 Mt) in 2002, and 33% (1,700 Mt) in 2005 (170). However, China's importation of forest products helped increase its forest cover at the cost of forest loss and degradation in exporting countries (171). A rough estimate indicates China's importation of 529 million m^3 of timber during 1994–2011 would have avoided the loss of 7.4 million ha of China's forest from harvesting, assuming an average timber stock volume of 71 m^3/ha (172). China's food import also saves much water and other resources such as land for food production. For instance, the water savings due to agricultural import increased from 33 km^3 in 2000 to 138 km^3 in 2009, equivalent to 37% of China's irrigation water use (173). These findings support the generally accepted premise that importing countries benefit environmentally from trade at the environmental expense of exporting countries. However, the latest evidence shows that with the importation of agricultural commodities, such as soybeans, China also suffers environmental damage through cropland conversion from soybeans to other crops such as maize and rice that use more fertilizers and water per unit of land, challenging the conventional wisdom regarding environmental impacts on importing versus exporting countries (174). This example demonstrates the need to consider the impacts of trade on subsequent land use and production in importing countries, not just evaluate the impacts of products imported from exporting countries. Furthermore, some pollutants emitted inside China as a result of producing goods for exports cross international borders, reaching adjacent countries such as Japan and Korea, and distant countries such as the United States (175).

The FDI has prompted the conversion of much farmland and natural land to built-up areas for factories and other types of infrastructure, thus generating negative environmental effects. However, a recent study using panel data from 112 Chinese cities for the period of 2002–2015 showed that FDI had a positive effect on air quality, as it reduced the per capita emissions of SO_2 and soot (176). This reduction may be due to enhanced resource use efficiencies through the transfers of environmentally friendly technology, services, and knowledge (176). However, some people in western countries have criticized China's ODI in less developed regions such as Africa and South America over the environment (177, 178).

Panda loans have socioeconomic and environmental effects across the world. Zoos hosting the pandas provide economic benefits to China, some of which have been used for panda conservation. Zoos spend considerable amounts of money on daily operation and facility construction. (For example, the construction of new facilities can cost more than US$10 million; 101). Visitors from other places pay for travel costs and entrance fees to see the pandas in the zoos. Panda loans enhance international scientific collaboration with staff in Wolong Nature Reserve. They also increase the awareness of the importance of panda conservation worldwide, although there is a substantial amount of CO_2 emissions due to transporting pandas from Wolong to the zoos, and travel of tourists to see the pandas in zoos (101).

6.3. Causes

The reasons behind the interactions between China and other countries are complex. They include a variety of factors, from economic, political, social, environmental, technological, and cultural, to legal. Furthermore, specific factors vary with the interactions. For example, a main economic cause of soybean import to China from Brazil (179) is a high demand for soybean products in China and an abundant supply of land, water, and capital for soybean production in Brazil. Ecologically, Brazil has good climatic conditions for growing soybeans twice a year. Culturally, the Chinese people have consumed soybean products for millennia and have been shifting their diet to a more animal-based one that uses soybeans as animal feed. Politically, the Chinese government is interested in increasing investments in other countries, and the Brazilian government is keen on expanding the export market. Technological causes include agronomic advances to produce high soybean yields in Brazil's acid *Cerrado* soils, new soybean varieties with symbiotic microorganisms in their roots that biologically fix nitrogen from the atmosphere, and development of supply chains, efficient storage, and long-distance transport (179).

Many international institutions and regulations play important roles in shaping the interactions between China and other countries. For example, the World Trade Organization, which China joined in 2001, deals with rules on trade between countries and enforces the relevant agreements. The Paris Climate Agreement (**http://unfccc.int/paris_agreement/items/9485.php**), in the development of which China played an important role, prompted China to commit to more environmental actions. Furthermore, China has adopted and is implementing the Aichi Targets (**https://www.cbd.int/sp/targets**) and Sustainable Development Goals (**http://www.un.org/sustainabledevelopment/sustainable-development-goals**). Panda loans to the United States are guided by the US Fish and Wildlife Service's policy on pandas' import (180). Although some countries such as the United States are increasing trade tariffs, China is actively promoting further trade and investment in other countries (e.g., through the Belt and Road Initiative; 181) and is willing to fill some of the global leadership vacuum.

7. TRANSFORMING CHINA'S ENVIRONMENTAL PROTECTION

To improve China's environment and promote ecological civilization—a goal established by the Chinese government to achieve harmony between humans and nature (182)—many issues need to be addressed. There are a wide range of measures, including increasing environmental standards (176), reinforcing environmental regulations (183), expanding green finance (184), implementing the new environmental tax law (185), replacing pollutant- and carbon-intensive production methods with environmental and energy-efficient technologies (186), accelerating the development and use of renewable and clean energy (187), upgrading vehicle gasoline quality (188), further developing more efficient and convenient public transportation systems to minimize the use of private vehicles (189), and eliminating or at least minimizing the waste of resources (190).

Although suggestions and practices such as those mentioned above are helpful, they are largely fragmented. To integrate various measures, we suggest taking systems approaches and applying the metacoupling framework (**Figure 12**) (12). Below we highlight two main strategies: (*a*) nexus approaches (linking various aspects of the environment and human dimensions), and (*b*) flow-centered governance (connecting movement of material, energy, information, people, capital, and organisms across different regions within China as well as between China and other countries nearby and far away).

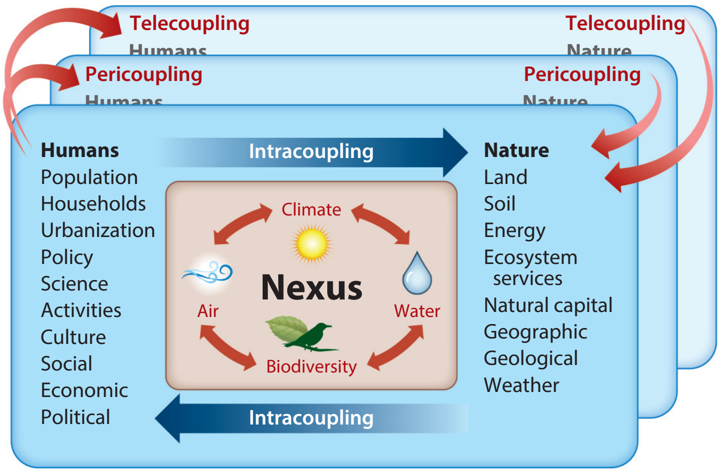

Figure 12

Conceptual framework of China's environment on a metacoupled planet. It integrates air quality, biodiversity, climate change, and water quantity and quality as an air-biodiversity-climate-water nexus. The nexus affects and is also affected by many other factors (e.g., energy, land, human population) as well as intracoupling (human-nature interactions within China), pericoupling (human-nature interactions between China and adjacent countries such as India), and telecoupling (human-nature interactions between China and distant countries such as the United States).

7.1. Nexus Approaches

China's policies usually target air pollution, climate change, water pollution and water shortage, or biodiversity separately (36, 191, 192). For example, policies on water pay little attention to air quality and climate change and biodiversity, whereas policies on air quality rarely explicitly consider biodiversity and water quality. However, different aspects of the environment interact with each other and may lead to cobenefits or trade-offs. For example, air pollutants end up in water bodies and surface runoff (e.g., acid rain; 193), affecting water quality. Constructing channels for water transfer reduces biodiversity, alters climate, and negatively impacts air quality through energy consumption and emissions of CO_2 as well as the production of waste and pollutants (11). There are also cobenefits of mitigating climate change while controlling air pollution (194, 195).

Various aspects of the environment and other factors need to be integrated using nexus approaches (196), which treat all aspects of the environment and relevant factors in a balanced and integrated manner. For instance, air and water interact with soils and form an air-soil-water nexus. This is important because soil pollution is a big challenge in China (197). A typical example to demonstrate such an air-soil-water nexus is the phosphorus cycling in Taihu Lake (China's third-largest freshwater lake with heavy water pollution). A study shows that the average emission of phosphine—PH_3—from the sediment of Taihu Lake to its waterbody was 28.3 g/year (198). Meanwhile, the average transfer of phosphite ($H_2PO_3^-$) from Taihu Lake's water into its sediment was 4.04 million mol/year (199), and the PH_3 flux at the water-air interface varied from -69.9 to 121 ng m^{-2} h^{-1}, with a mean flux of 14.4 ng m^{-2} h^{-1} (200). The air-soil-water nexus also interacts with bacteria, plants, and animals; influences biodiversity; shapes ecosystem functions and services; and affects ecosystem and human health.

Factors affected by the environment and those affecting the environment, such as the health impacts of the environment, and environmental impacts of alternative energy sources and farming practices, should be considered simultaneously in research, policy making and management. For example, the water-food-energy-climate nexus (201) addresses interactions among water, food, energy, and climate at the same time. Including more aspects of the environment and more relevant factors greatly increases the complexity, such as the number of potential interactions. However, these studies are also potentially more rewarding. Linking environmental issues with other factors such as human health, longevity, and food safety can help policymakers and the general public pay more serious attention to the environment and take more effective measures to enhance synergies and minimize trade-offs.

Improving resource use efficiency is important for reducing China's environmental problems, and it is emphasized in almost all policy documents and recommendations. Although average per capita consumption in China is still lower than that in the United States, many wealthy individuals and households in China are already overconsuming and setting the consumption trend for the rest of the country. Therefore, one particular method to improve resource use efficiency is to reduce overconsumption. However, efficiency gains may be cancelled out by increasing demands such as those caused by the continuing rapid economic growth and household proliferation. To reduce or avoid such offsetting (rebound) effects, a fundamental shift from the current focus on supply management to demand management can play a crucial role. For instance, although much attention has been paid to population growth, the number of households has actually been increasing much faster than population size (202). Because much of the ultimate demand originates at the household level, reducing household demand is crucial.

The recent changes to China's environmental governance structure are expected to facilitate nexus approaches and make environmental protection more effective (203). There are many adjustments of responsibilities for better coordination and consideration of interactions among different aspects of the environment (17). The new Ministry of Ecology and Environment adopts most of the responsibilities of the Ministry of Environmental Protection and takes over some environment-related functions from several other agencies, such as climate change–related functions (e.g., management of carbon emissions) from the National Development and Reform Commission. The new Ministry of Natural Resources merges the responsibilities of managing natural resources that belonged to various governmental agencies. The new State Forestry and Grassland Administration expands the functions of the previous State Forestry Administration by including grassland management.

7.2. Flow-Centered Governance

It is important to expand environmental protection from place-based to flow-centered governance (i.e., from a particular place to multiple places that are coupled through various flows). Such an expansion could help link different places as an integrated whole. Flow-centered governance emphasizes that environmental protection in one place should consider its relationships with other places nearby and far away. A place can be a region such as a county or province within China or an entire country such as China. As illustrated in previous sections, achieving environmental quality in one place may enhance or compromise environmental quality in other places. However, current environmental protection often focuses on a specific place (204), or one aspect of environmental, social, and economic outcomes (205). For example, without the development of suitable policies that pay attention to spillover effects, such as carbon leakages, less developed regions usually suffer environmentally, whereas more developed regions may experience environmental gains by outsourcing production (126). This, therefore, creates environmental inequality and makes the United Nations' Sustainable Development Goals (**http://www.un.org/sustainabledevelopment/sustainable-development-goals**) unachievable.

The new integrated framework of metacoupling can account for human-environment interactions within a specific place, between adjacent places, and between distant places (12) (**Figure 12**). It enables an interdisciplinary perspective to examine socioeconomic and environmental causes, effects, and flows between places facilitated by various agents such as policymakers and traders. For example, to reduce pollution in cities such as Beijing, many polluting factories have been relocated to less developed places (204, 206), but the total pollution may actually increase because the less developed places often have less environmental policy enforcement.

Another advantage of flow-centered governance is the explicit recognition that there are feedbacks across sectors within a place, across places, and across scales. They are usually ignored because they are often difficult to detect, and because they do not appear in the short term. However, the consequences of feedbacks can be profound (207). Thus, it is important to develop coordinated policies for environmental management across regions, among sectors, and over time. For example, air pollution prevention and control policies for a particular city or region should consider spillover effects and develop joint efforts with other cities or regions. These may include collaborative research on metacoupling, synchronized monitoring, information sharing, and development of early warning mechanisms.

To effectively implement flow-centered governance, it is important to understand the driving forces behind the flows and systematically assess and predict policy outcomes. Government officials are often more interested in knowing what will happen than what has already occurred. To help policymakers understand potential environmental and socioeconomic outcomes and take proactive adaptive governance measures, it is necessary to monitor indicators that drive environmental changes directly and indirectly, and to construct system models that simulate different policy scenarios (143, 205). Government agencies and nongovernmental organizations should expand environmental monitoring, especially in environmentally sensitive areas and areas with severe water shortages, to socioeconomic indicators (e.g., environmental values and attitudes, and development).

8. CONCLUDING REMARKS

China's environment is a mix of hope, concern, and uncertainty. The overall quality of air and water has begun to get better, but there is a long way to go to recover and reach the national, and especially international, standards. While some aspects of the environment (e.g., water shortage and biodiversity) are still deteriorating, other aspects (e.g., forest cover, carbon sequestration, soil retention, water retention, flood mitigation, sandstorm prevention) are improving. With more affluence, demands for domestic and foreign goods will continue to escalate. Under the government's push for more rapid urbanization, urban land area will keep expanding although it is uncertain how much agricultural and natural land will be converted for urban uses as it will depend on the enforcement of relevant policies. A metacoupled human and natural systems approach to integrate all aspects of the environment and relevant factors (e.g., reciprocal interactions between China and other countries) will help illuminate China's future environment and enhance governance. All of these have important implications for both China's ecological civilization and other global efforts such as the Sustainable Development Goals, Aichi Targets, and Paris Climate Agreement. China has been rapidly moving toward the global environmental leadership position that Liu & Diamond (10) called for in 2005. In fact, China has already taken the lead in several aspects such as renewable energy (187), and further efforts should accelerate this process. Thus, the time is ripe for revolutionizing environmental protection toward a true human-nature harmony in China and beyond, on a metacoupled planet.

SUMMARY POINTS

1. After four decades of unprecedented economic growth, China has emerged as the second largest global economy, but also is facing many environmental challenges with enormous ecological, socioeconomic, and health consequences in China and beyond.
2. To address the widespread environmental problems, China has been implementing a series of large national environmental programs (e.g., Natural Forest Conservation Program, Grain-to-Green Program, Ecosystem Functional Conservation Areas, Ecological Protection Redlines, and National Park System).
3. While some aspects of the environment (e.g., water shortage and biodiversity) are still deteriorating, hopeful signs have emerged with the increase in forest cover, recovery of some endangered and threatened species such as the giant panda, and improvement in some key ecosystem services.
4. China has been moving toward a global environmental leadership position and has been sharing more global environmental responsibilities (e.g., leading and/or participating in the adoption of the Sustainable Development Goals, Aichi Targets, and Paris Climate Agreement).
5. A metacoupled human and natural systems approach will promote China's environmental governance, accelerate the process towards ecological civilization, and benefit global efforts toward the Sustainable Development Goals, Aichi Targets, and Paris Climate Agreement.

FUTURE ISSUES

1. China's environmental governance should adopt nexus approaches (e.g., air-soil-water nexus, water-food-energy-climate nexus), which treat all aspects of the environment and relevant factors in a balanced and integrated manner.
2. Future research and environmental management need to switch from a place-based to flow-centered approach (i.e., from a particular place to multiple places that are coupled through various flows).
3. Future research and management also need to pay special attention to spillover effects to enhance synergies and minimize trade-offs among different sectors, societal groups, and places.
4. To improve policy design and implementation, it is important to systematically and rigorously assess the environmental and socioeconomic outcomes of existing policies at various scales, especially the large national environmental programs.
5. To more accurately predict environmental and socioeconomic outcomes of existing or new policies and take proactive adaptive governance measures, it is crucial to monitor indicators that drive environmental and socioeconomic changes directly and indirectly, and to construct system models that simulate long-term consequences of different policy scenarios.

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LITERATURE CITED

1. Hawkins J, Ma CB, Schilizzi S, Zhang F. 2018. China's changing diet and its impacts on greenhouse gas emissions: an index decomposition analysis. *Aust. J. Agric. Resour. Econ.* 62:45–64
2. Li H, Wei YD, Ning YM. 2016. Spatial and temporal evolution of urban systems in China during rapid urbanization. *Sustainability* 8:671
3. Norse D, Ju XT. 2015. Environmental costs of China's food security. *Agric. Ecosyst. Environ.* 209:5–14
4. State Council of the People's Republic of China. 2016. *State Council's Notice on Distributing the Construction Plan of China to Implement 2030 Sustainable Development Agenda for Innovation Demonstration Zone* (in Chinese). Beijing: State Counc. PRC. **http://www.gov.cn/zhengce/content/2016-12/13/content_5147412.htm**
5. Liu J, Li S, Ouyang Z, Tam C, Chen X. 2008. Ecological and socioeconomic effects of China's policies for ecosystem services. *PNAS* 105:9477–82
6. Ministry of Environmental Protection of China. 2017. *Promoting Ecological Civilization and Harmonizing Human-Nature Relationship* (in Chinese). Beijing: Ministry Environ. Protect. China. **http://www.mep.gov.cn/gkml/hbb/qt/201712/t20171210_427677_wap.shtml**
7. Viña A, McConnell WJ, Yang H, Xu Z, Liu J. 2016. Effects of conservation policy on China's forest recovery. *Sci. Adv.* 2:e1500965
8. Yang H, Viña A, Tang Y, Zhang J, Wang F, et al. 2017. Range-wide evaluation of wildlife habitat change: a demonstration using Giant Pandas. *Biol. Conserv.* 213:203–9
9. Ouyang Z, Zheng H, Xiao Y, Polasky S, Liu J, et al. 2016. Improvements in ecosystem services from investments in natural capital. *Science* 352:1455–59
10. Liu J, Diamond J. 2005. China's environment in a globalizing world. *Nature* 435:1179–86
11. Liu J, Raven PH. 2010. China's environmental challenges and implications for the world. *Crit. Rev. Environ. Sci. Technol.* 40:823–51
12. Liu J. 2017. Integration across a metacoupled world. *Ecol. Soc.* 22:29
13. Ministry of Ecology and Environment of China. 2017. *Bulletin of China's Ecology and Environment in 2017* (in Chinese). **http://www.mep.gov.cn/gkml/sthjbgw/qt/201805/W020180531606576563901.pdf**
14. Zhan D, Kwan MP, Zhang W, Wang S, Yu J. 2017. Spatiotemporal variations and driving factors of air pollution in China. *Int. J. Environ. Res. Public Health* 14:1538
15. Cheng ZH, Li LS, Liu J. 2017. Identifying the spatial effects and driving factors of urban $PM_{2.5}$ pollution in China. *Ecol. Indic.* 82:61–75
16. Guo H, Cheng T, Gu X, Wang Y, Chen H, et al. 2017. Assessment of PM2.5 concentrations and exposure throughout China using ground observations. *Sci. Total Environ.* 601:1024–30
17. *sohu.com.* 2018. First Minister Li Ganjie: The Ministry of Ecology and Environment is to coordinate mountains, water, forests, croplands, lakes and grasslands *(in Chinese)*. *sohu.com*, March 19. **http://www.sohu.com/a/225848901_114986**
18. Hao Y, Peng H, Temulun T, Liu L-Q, Mao J, et al. 2018. How harmful is air pollution to economic development? New evidence from $PM_{2.5}$ concentrations of Chinese cities. *J. Cleaner Prod.* 172:743–57

19. *Xinhuanet*. 2016. The capacity of the Beijing Capital International Airport decreased by about 30% due to heavy fog and severe haze *(in Chinese)*. *Xinhuanet*, Dec. 21. **http://www.xinhuanet.com/2016-12/21/c_1120155756.htm**
20. *Beijing.gov.cn*. 2016. Education: Elementary and secondary schools, and kindergarten closed (in Chinese). *Beijing.gov.cn*. **http://zhengwu.beijing.gov.cn/zwzt/jjydkqzwr/ywcz/t1413358.htm**
21. *Beijing Daily*. 2018. Beijing: early orange warning of heavy air pollution *(in Chinese)*. *Beijing Daily*, Jan. 12. **http://www.gov.cn/xinwen/2018-01/12/content_5255851.htm**
22. *Beijing.gov.cn*. 2016. Health: Beijing CDC released health tips *(in Chinese)*. *Beijing.gov.cn*. **http://zhengwu.beijing.gov.cn/zwzt/jjydkqzwr/ywcz/t1413355.htm**
23. *Associated Press*. 2018. Major Chinese city orders traffic, factory curbs due to smog. *Associated Press*, March 10. **http://www.dailystar.com.lb/Life/Environment/2018/Mar-10/441014-major-chinese-city-orders-traffic-factory-curbs-due-to-smog.ashx**
24. Xia Y, Guan DB, Jiang XJ, Peng LQ, Schroeder H, Zhang Q. 2016. Assessment of socioeconomic costs to China's air pollution. *Atmos. Environ.* 139:147–56
25. Chen C, Zhu PF, Lan L, Zhou L, Liu RC, et al. 2018. Short-term exposures to $PM_{2.5}$ and cause-specific mortality of cardiovascular health in China. *Environ. Res.* 161:188–94
26. Maji KJ, Dikshit AK, Arora M, Deshpande A. 2018. Estimating premature mortality attributable to $PM_{2.5}$ exposure and benefit of air pollution control policies in China for 2020. *Sci. Total Environ.* 612:683–93
27. World Health Organization. 2016. WHO ambient (outdoor) air quality and health. *WHO*, May 2. **http://www.who.int/mediacentre/factsheets/fs313/en**
28. Chen YY, Ebenstein A, Greenstone M, Li HB. 2013. Evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai River policy. *PNAS* 110:12936–41
29. Ebenstein A, Fan MY, Greenstone M, He GJ, Zhou MG. 2017. New evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai River Policy. *PNAS* 114:10384–89
30. Baciak M, Warmiński K, Bęś A. 2015. The effect of selected gaseous air pollutants on woody plants. *For. Res. Pap.* 76:401–9
31. Li FR, Kang LF, Gao XQ, Hua W, Yang FW, Hei WL. 2007. Traffic-related heavy metal accumulation in soils and plants in northwest China. *Soil Sediment Contam.* 16:473–84
32. Chen YP, Zheng YJ, Liu Q, Song Y, An ZS, et al. 2017. Atmospheric deposition exposes Qinling pandas to toxic pollutants. *Ecol. Appl.* 27:343–48
33. Bai C. 2017. Research progress on formation mechanism and control strategies of haze in Chinese Academy of Sciences. *Bull. Chinese Acad. Sci.* 32:215–18
34. National Bureau of Statistics of China. 2016–2017. *China Statistical Yearbook*. Beijing: China Statistics Press
35. Gao P, Sha S, Zipser D, Baan W. 2016. Finding the fast lane: emerging trends in China's auto market. *McKinsey&Company*, April. **http://www.mckinsey.com/industries/automotive-and-assembly/our-insights/finding-the-fast-lane-emerging-trends-in-chinas-auto-market**
36. State Council of the People's Republic of China. 2013. *State Council's Notice on Distributing the Action Plan of Air Pollution Prevention and Control* (in Chinese). Beijing: State Counc. PRC. **http://www.gov.cn/zwgk/2013-09/12/content_2486773.htm**
37. State Council of the People's Republic of China. 2014. *Measures to Evaluate the Implementation of the Action Plan on Air Pollution Prevention and Control (Provisional)* (in Chinese). Beijing: State Counc. PRC. **http://www.gov.cn/zhengce/content/2014-05/27/content_8830.htm**
38. *People's Daily*. 2014. Air pollution control is not a money losing business *(in Chinese)*. *People's Daily*, March 15. **http://env.people.com.cn/n/2014/0315/c1010-24641811.html**
39. Zheng YX, Xue T, Zhang Q, Geng GN, Tong D, et al. 2017. Air quality improvements and health benefits from China's clean air action since 2013. *Environ. Res. Lett.* 12:114020
40. Wang Y, Liu HW, Mao GZ, Zuo J, Ma JL. 2017. Inter-regional and sectoral linkage analysis of air pollution in Beijing-Tianjin-Hebei (Jing-Jin-Ji) urban agglomeration of China. *J. Cleaner Prod.* 165:1436–44
41. Wang HK, Zhang YX, Zhao HY, Lu X, Zhang YX, et al. 2017. Trade-driven relocation of air pollution and health impacts in China. *Nat. Commun.* 8:738
42. Huang J, Lu X, Huang J, Ma K. 2016. Conservation priority of endemic Chinese flora at family and genus levels. *Biodivers. Conserv.* 25:23–35

43. Liu J, Ouyang Z, Pimm SL, Raven PH, Wang X, et al. 2003. Protecting China's biodiversity. *Science* 300:1240–41
44. Wang L, Jia Y, Zhang X, Qin H. 2015. Overview of higher plant diversity in China. *Biodivers. Sci.* 23:217–24
45. Pitman NCA, Jørgensen PM. 2002. Estimating the size of the World's threatened flora. *Science* 298:989
46. Catalogue of Life China. 2018. Annual Checklist. Leiden, Neth.: Catalogue Life China. **http://www.sp2000.org.cn/2018**
47. Xu W, Viña A, Kong L, Pimm SL, Zhang J, et al. 2017. Reassessing the conservation status of the giant panda using remote sensing. *Nat. Ecol. Evol.* 1:1635–38
48. Sun Y, Wang T, Skidmore AK, Wang Q, Ding C. 2015. Decline of traditional rice farming constrains the recovery of the endangered Asian crested ibis (*Nipponia nippon*). *Ambio* 44:803–14
49. Leclerc C, Bellard C, Luque GM, Courchamp F. 2015. Overcoming extinction: understanding processes of recovery of the Tibetan antelope. *Ecosphere* 6:1–14
50. Shen Y, Wang P, Wang C, Yu Y, Kong N. 2018. Potential causes of habitat degradation and spawning time delay of the Chinese sturgeon (*Acipenser sinensis*). *Ecol. Informatics* 43:96–105
51. Wang T, Royle JA, Smith JL, Zou L, Lü X, et al. 2018. Living on the edge: opportunities for Amur tiger recovery in China. *Biol. Conserv.* 217:269–79
52. Turvey ST, Pitman RL, Taylor BL, Barlow J, Akamatsu T, et al. 2007. First human-caused extinction of a cetacean species? *Biol. Lett.* 3:537–40
53. Ministry of Environmental Protection of China, Chinese Academy of Sciences. 2013. *Assessment report on the Red List of China's biodiversity—higher plants* (in Chinese). Announc. 54, Min. Environ. Protect. China, Chinese Acad. Sci., Beijing. **http://www.mep.gov.cn/gkml/hbb/bgg/201309/t20130912_260061.htm**
54. Ministry of Environmental Protection of China, Chinese Academy of Sciences. 2015. *Assessment report on the Red List of China's biodiversity—vertebrates* (in Chinese). Announc. 32, Min. Environ. Protect. China, Chinese Acad. Sci., Beijing. **http://www.zhb.gov.cn/gkml/hbb/bgg/201505/t20150525_302233.htm**
55. Jiang B, Wong CP, Chen Y, Cui L, Ouyang Z. 2015. Advancing wetland policies using ecosystem services—China's way out. *Wetlands* 35:983–95
56. Zheng Y, Zhang H, Niu Z, Gong P. 2012. Protection efficacy of national wetland reserves in China. *Chinese Sci. Bull.* 57:1116–34
57. Li BV, Pimm SL. 2016. China's endemic vertebrates sheltering under the protective umbrella of the giant panda. *Conserv. Biol.* 30:329–39
58. Teichroew JL, Xu J, Ahrends A, Huang ZY, Tan K, Xie Z. 2017. Is China's unparalleled and understudied bee diversity at risk? *Biol. Conserv.* 210:19–28
59. Castañeda-Álvarez NP, Khoury CK, Achicanoy HA, Bernau V, Dempewolf H, et al. 2016. Global conservation priorities for crop wild relatives. *Nat. Plants* 2:16022
60. Pavlidis G, Tsihrintzis V. 2017. Pollution control by agroforestry systems: a short review. *Eur. Water* 59:297–301
61. Zeng L, He F, Dai Z, Xu D, Liu B, et al. 2017. Effect of submerged macrophyte restoration on improving aquatic ecosystem in a subtropical, shallow lake. *Ecol. Eng.* 106:578–87
62. Zou Y, Xiao H, Bianchi FJ, Jauker F, Luo S, van der Werf W. 2017. Wild pollinators enhance oilseed rape yield in small-holder farming systems in China. *BMC Ecol*. 17:6
63. Zomer RJ, Neufeldt H, Xu J, Ahrends A, Bossio D, et al. 2016. Global tree cover and biomass carbon on agricultural land: the contribution of agroforestry to global and national carbon budgets. *Sci. Rep.* 6:29987
64. Huang Y, Ma Y, Zhao K, Niklaus PA, Schmid B, He J-S. 2017. Positive effects of tree species diversity on litterfall quantity and quality along a secondary successional chronosequence in a subtropical forest. *J. Plant Ecol*. 10:28–35
65. Brezzi M, Schmid B, Niklaus PA, Schuldt A. 2017. Tree diversity increases levels of herbivore damage in a subtropical forest canopy: evidence for dietary mixing by arthropods? *J. Plant Ecol.* 10:13–27
66. Peng S, Schmid B, Haase J, Niklaus PA. 2016. Leaf area increases with species richness in young experimental stands of subtropical trees. *J. Plant Ecol.* 10:128–35

67. Sun Z, Liu X, Schmid B, Bruelheide H, Bu W, Ma K. 2017. Positive effects of tree species richness on fine-root production in a subtropical forest in SE-China. *J. Plant Ecol.* 10:146–57
68. Lefcheck JS, Byrnes JE, Isbell F, Gamfeldt L, Griffin JN, et al. 2015. Biodiversity enhances ecosystem multifunctionality across trophic levels and habitats. *Nat. Commun.* 6:6936
69. Song W, Deng X. 2017. Land-use/land-cover change and ecosystem service provision in China. *Sci. Total Environ.* 576:705–19
70. Xu Y, Lin S, He J, Xin Y, Zhang L, et al. 2017. Tropical birds are declining in the Hainan Island of China. *Biol. Conserv.* 210:9–18
71. Volis S. 2016. How to conserve threatened Chinese plant species with extremely small populations? *Plant Divers*. 38:45–52
72. Ding C, Jiang X, Xie Z, Brosse S. 2017. Seventy-five years of biodiversity decline of fish assemblages in Chinese isolated plateau lakes: widespread introductions and extirpations of narrow endemics lead to regional loss of dissimilarity. *Divers. Distrib.* 23:171–84
73. Peng J, Zong M, Hu Yn, Liu Y, Wu J. 2015. Assessing landscape ecological risk in a mining city: a case study in Liaoyuan City, China. *Sustainability* 7:8312–34
74. Li YZ, Chen XS, Xie YH, Li X, Li F, Hou ZY. 2014. Effects of young poplar plantations on understory plant diversity in the Dongting Lake wetlands, China. *Sci. Rep.* 4:6339
75. Wang P, Dong S, Lassoie JP. 2014. Environmental impacts of dams in china: focusing on biological diversity and ecological integrity. In *The Large Dam Dilemma*, ed. P Wang, S Dong, JP Lassoie, pp. 43–75. Dordrecht, Neth.: Springer
76. Liu C, He D, Chen Y, Olden JD. 2017. Species invasions threaten the antiquity of China's freshwater fish fauna. *Divers. Distrib.* 23:556–66
77. Ye J, Wu M, Deng Z, Xu S, Zhou R, Clarke KC. 2017. Modeling the spatial patterns of human wildfire ignition in Yunnan province, China. *Appl. Geogr.* 89:150–62
78. Zou Y, Wang L, Xue Z, Mingju E, Jiang M, et al. 2018. Impacts of agricultural and reclamation practices on wetlands in the Amur River Basin, northeastern China. *Wetlands* 38:383–89
79. Zhao N, Li M, Luo J, Wang S, Liu S, et al. 2017. Impacts of canine distemper virus infection on the giant panda population from the perspective of gut microbiota. *Sci. Rep.* 7:39954
80. Xu W, Xiao Y, Zhang J, Yang W, Zhang L, et al. 2017. Strengthening protected areas for biodiversity and ecosystem services in China. *PNAS* 114:1601–6
81. Zhang J, Hull V, Xu W, Liu J, Ouyang Z, et al. 2011. Impact of the 2008 Wenchuan earthquake on biodiversity and giant panda habitat in Wolong Nature Reserve, China. *Ecol. Res.* 26:523–31
82. Feng YY, Bantillo P. 2017. China sets 15% non-fossil energy consumption target by 2020. *ICIS*, Jan. 20. **https://www.icis.com/resources/news/2017/01/20/10071365/china-sets-15-non-fossil-energy-consumption-target-by-2020**
83. Zhao G, Liu J, Kuang W, Ouyang Z, Xie Z. 2015. Disturbance impacts of land use change on biodiversity conservation priority areas across China: 1990–2010. *J. Geogr. Sci.* 25:515–29
84. Liu J, Kuang W, Zhang Z, Xu X, Qin Y, et al. 2014. Spatiotemporal characteristics, patterns and causes of land use changes in China since the late 1980s. *Acta Geogr. Sin.* 69:3–14
85. Liu J-J, Slik JF. 2014. Forest fragment spatial distribution matters for tropical tree conservation. *Biol. Conserv.* 171:99–106
86. Liu J, Hull V, Yang W, Viña A, Chen X, et al. 2016. *Pandas and People: Coupling Human and Natural Systems for Sustainability*. Oxford, UK: Oxford Univ. Press
87. Kargbo AB. 2017. China ensures strict supervision on wildlife trade. *People's Daily Online*, Sept. 27. **http://en.people.cn/n3/2017/0927/c90000-9274404.html**
88. Xu J, Wilkes A. 2004. Biodiversity impact analysis in northwest Yunnan, southwest China. *Biodivers. Conserv.* 13:959–83
89. Zhang L, Luo Z, Mallon D, Li C, Jiang Z. 2017. Biodiversity conservation status in China's growing protected areas. *Biol. Conserv.* 210:89–100
90. Ministry of Environmental Protection of China, Chinese Academy of Sciences. 2015. *National Ecosystem Service Zoning in China* (in Chinese). Beijing: Minist. Environ. Protect. China

91. Ministry of Environmental Protection of China, National Development and Reform Commission of China. 2017. *Guidelines on the Ecological Redline Strategy* (in Chinese). Beijing: Minist. Environ. Protect. China
92. Central Committee of the Chinese Communist Party and State Council. 2018. *Plans for Comprehensively Strengthening Environmental Protection and Resolutely Fighting the War Against Pollution* (in Chinese). **http://www.gov.cn/zhengce/2018-06/24/content_5300953.htm**
93. Ouyang Z, Xu W, Du A, Lei G, Zhu C, Chen S. 2018. *Research on Overall Spatial Planning for China's National Park System* (in Chinese). Beijing: Sci. China Press. In press
94. Li W, Clauzel C, Dai Y, Wu G, Giraudoux P, Li L. 2017. Improving landscape connectivity for the Yunnan snub-nosed monkey through cropland reforestation using graph theory. *J. Nat. Conserv.* 38:46–55
95. Chen Y, Liu Y, Fan X, Li W, Liu Y. 2017. Landscape-scale genetic structure of wild rice *Zizania latifolia*: the roles of rivers, mountains and fragmentation. *Front. Ecol. Evol.* 5. **https://doi.org/10.3389/fevo.2017.00017**
96. Liang J, He X, Zeng G, Zhong M, Gao X, et al. 2018. Integrating priority areas and ecological corridors into national network for conservation planning in China. *Sci. Total Environ.* 626:22–29
97. Wang CJ, Cheng JJ. 2016. Spatial pattern of expressway network accessibility and evolution in China. *Sci. Geogr. Sin.* 36:803–12
98. Stockstad E. 2018. China moves to protect coastal wetlands used by migratory birds. *Science*, Jan. 30. **http://www.sciencemag.org/news/2018/01/china-moves-protect-coastal-wetlands-used-migratory-birds**
99. *Xinhuanet*. 2018. China focus: China introduces toughest ever regulation on land reclamation. *Xinhuane*t, Jan. 18. **http://www.xinhuanet.com/english/2018-01/18/c_136903321.htm**
100. Clayton S, Bexell S, Ping X, Zhihe Z, Jing LW, et al. 2018. Confronting the wildlife trade through public education at zoological institutions in Chengdu, PR China. *Zoo Biol.* 37:119–29
101. Liu J, Hull V, Luo J, Yang W, Liu W, et al. 2015. Multiple telecouplings and their complex interrelationships. *Ecol. Soc.* 20:44
102. Wong RW. 2017. "Do you know where I can buy ivory?": The illegal sale of worked ivory products in Hong Kong. *Aust. New Zeal. J. Criminol.* 51:204–20
103. Nijman V, Nekaris KA-I, Bickford DP. 2012. Asian medicine: small species at risk. *Nature* 481:265
104. Wang Y, Zheng H, Xie Z, Wang Y. 2012. Exploitation of wild Chinese herbs leads to environmental degradation and possible loss of the resource. *Environ. Sci. Technol.* 46:1307–8
105. Lian Y, You GJ-Y, Lin K, Jiang Z, Zhang C, Qin X. 2015. Characteristics of climate change in southwest China karst region and their potential environmental impacts. *Environ. Earth Sci.* 74:937–44
106. Piao S, Ciais P, Huang Y, Shen Z, Peng S, et al. 2010. The impacts of climate change on water resources and agriculture in China. *Nature* 467:43–51
107. Chen S, Chen X, Xu J. 2016. Impacts of climate change on agriculture: evidence from China. *J. Environ. Econ. Manag.* 76:105–24
108. Yao T, Thompson L, Yang W, Yu W, Gao Y, et al. 2012. Different glacier status with atmospheric circulations in Tibetan Plateau and surroundings. *Nat. Clim. Change* 2:663–67
109. Fu B, Guo Q, Yan F, Zhang J, Shi P, et al. 2017. Glacier retreat of the Tian Shan and its impact on the urban growth and environment evaluated from satellite remote sensing data. *IOP Conf. Ser.: Earth Environ. Sci.* 74:012022
110. Ge Q, ed. 2007. *China's Climate Resources and Sustainable Development*, Vol. 7 (in Chinese). Beijing: Sci. Press
111. Wang W, Xiang Y, Gao Y, Lu A, Yao T. 2015. Rapid expansion of glacial lakes caused by climate and glacier retreat in the Central Himalayas. *Hydrol. Proc.* 29:859–74
112. Ge Q, Wang H, Dai J. 2015. Phenological response to climate change in China: a meta-analysis. *Glob. Change Biol.* 21:265–74
113. Zhang MG, Zhou ZK, Chen WY, Cannon CH, Raes N, Slik J. 2014. Major declines of woody plant species ranges under climate change in Yunnan, China. *Divers. Distrib.* 20:405–15
114. Zhao M, Running SW. 2010. Drought-induced reduction in global terrestrial net primary production from 2000 through 2009. *Science* 329:940–43

115. Yuan Q, Wu S, Dai E, Zhao D, Ren P, Zhang X. 2017. NPP vulnerability of the potential vegetation of China to climate change in the past and future. *J. Geogr. Sci.* 27:131–42
116. Shi W, Liu Y, Shi X. 2018. Contributions of climate change to the boundary shifts in the farming-pastoral ecotone in northern China since 1970. *Agric. Syst.* 161:16–27
117. Yang X, Chen F, Lin X, Liu Z, Zhang H, et al. 2015. Potential benefits of climate change for crop productivity in China. *Agric. Forest Meteorol.* 208:76–84
118. Lin Y, Feng Z, Wu W, Yang Y, Zhou Y, Xu C. 2017. Potential impacts of climate change and adaptation on maize in northeast China. *Agronomy J.* 109:1476–90
119. Tilman D, Balzer C, Hill J, Befort BL. 2011. Global food demand and the sustainable intensification of agriculture. *PNAS* 108:20260–64
120. Tong MX, Hansen A, Hanson-Easey S, Cameron S, Xiang J, et al. 2015. Infectious diseases, urbanization and climate change: challenges in future China. *Int. J. Environ. Res. Public Health* 12:11025–36
121. Ren Z, Wang D, Ma A, Hwang J, Bennett A, et al. 2016. Predicting malaria vector distribution under climate change scenarios in China: challenges for malaria elimination. *Sci. Rep.* 6:20604
122. Li Y, Ren T, Kinney PL, Joyner A, Zhang W. 2018. Projecting future climate change impacts on heat-related mortality in large urban areas in China. *Environ. Res.* 163:171–85
123. Chen K, Horton RM, Bader DA, Lesk C, Jiang L, et al. 2017. Impact of climate change on heat-related mortality in Jiangsu Province, China. *Environ. Poll.* 224:317–25
124. Hu X, Wu J, Chen P, Sun T, Li D. 2017. Impact of climate variability and change on crime rates in Tangshan, China. *Sci. Total Environ.* 609:1041–48
125. International Energy Agency (IEA). 2017. *CO_2 Emissions from Fuel Combustion—Highlights*. Paris: IEA Publ. **https://www.iea.org/publications/freepublications/publication/CO2EmissionsfromFuelCombustionHighlights2017.pdf**
126. Feng K, Davis SJ, Sun L, Li X, Guan D, et al. 2013. Outsourcing CO_2 within China. *PNAS* 110:11654–59
127. *Xinhuanet*. 2016. The 13th Five-Year Plan for Economic and Social Development of the People's Republic of China *(in Chinese)*. *Xinhuanet*, March 17. **http://www.xinhuanet.com/politics/2016lh/2016-03/17/c_1118366322_12.htm**
128. Huang L, Liu JY, Shao QQ, Xu XL. 2012. Carbon sequestration by forestation across China: past, present, and future. *Renew. Sustain. Energy Rev.* 16:1291–99
129. Lu F, Hu H, Sun W, Zhu J, Liu G, et al. 2018. Effects of national ecological restoration projects on carbon sequestration in China from 2001 to 2010. *PNAS*. 115:4039–44
130. Xu L, Wen D, Zhu J, He N. 2017. Regional variation in carbon sequestration potential of forest ecosystems in China. *Chinese Geogr. Sci.* 27:337–50
131. Gao S, Zhao X, Fang J. 2016. Carbon sequestration of grassland in China (in Chinese). *Strateg. Study Chinese Acad. Eng.* 18:73–79
132. Fang J, Yu G, Liu L, Hu S, Chapin FS 3rd. 2018. Climate change, human impacts, and carbon sequestration in China. *PNAS* 115: 4015–20
133. National Bureau of Statistics of China. 2008. *China Provincial Statistics Yearbook*. Beijing: China Statistics Press
134. Ministry of Water Resources of China. 2017. *Chinese Water Resources Bulletin 2016* (in Chinese). Beijing: China Water Power Press
135. Cui NX, Wu J, Xiang DF, Cheng SP, Zhou Q. 2013. A field study on seed bank and its potential applications in vegetation restoration of a polluted urban river in China. *Ecol. Eng.* 60:37–44
136. National Bureau of Statistics of China, State Environmental Protection Administration of China. 2015. *China Statistical Yearbook on Environment*. Beijing: China Statistics Press
137. Cui NX, Wu J, Dai YR, Li Z, Cheng SP. 2017. Influence of nitrogen loading and flooding on seedling emergence and recruitment from a seed bank in Chaohu Lake Basin, China. *Environ. Sci. Pollut. Res.* 24:22688–97
138. Mekonnen MM, Hoekstra AY. 2016. Four billion people facing severe water scarcity. *Sci. Adv.* 2:e1500323
139. Shi XQ, Jiang SM, Xu HX, Jiang F, He ZF, Wu JC. 2016. The effects of artificial recharge of groundwater on controlling land subsidence and its influence on groundwater quality and aquifer energy storage in Shanghai, China. *Environ. Earth Sci.* 75:1–18

140. Guo HP, Zhang ZC, Cheng GM, Li WP, Li TF, Jiao JJ. 2015. Groundwater-derived land subsidence in the North China Plain. *Environ. Earth Sci.* 74:1415–27
141. Lu YL, Song S, Wang RS, Liu ZY, Meng J, et al. 2015. Impacts of soil and water pollution on food safety and health risks in China. *Environ. Int.* 77:5–15
142. Ding L, Chen KL, Cheng SG, Wang X. 2015. Water ecological carrying capacity of urban lakes in the context of rapid urbanization: a case study of East Lake in Wuhan. *Phys. Chem. Earth* 89–90:104–13
143. Liu J, Yang W. 2012. Water sustainability for China and beyond. *Science* 337:649–50
144. Ding N, Liu JR, Yang JX, Lu B. 2018. Water footprints of energy sources in China: exploring options to improve water efficiency. *J. Cleaner Prod.* 174:1021–31
145. National Bureau of Statistics of China. 2014. *Statistical Data on Environment 2014* (in Chinese). Beijing: Nat. Bur. Stat. China. **http://www.stats.gov.cn/ztjc/ztsj/hjtjzl/2014**
146. Ministry of Water Resources of China. 2017. *2016 Statistic Bulletin on China Water Activities*. Beijing: China Water and Power Press
147. *inquirer.net*. 2017. Beijing evicts Chinese domestic migrants in droves, prompting outcry. *Associated Press*, Nov. 28. **http://newsinfo.inquirer.net/948306/beijing-evicts-chinese-domestic-migrants-in-droves-prompting-outcry**
148. The Guardian. 2017. Endless cities: Will China's new urbanisation just mean more sprawl? *The Guardian*, May 7. **https://www.theguardian.com/cities/2017/may/05/megaregions-endless-china-urbanisation-sprawl-xiongan-jingjinji**
149. Zhang FR. 2013. Prediction of China's water shortage in the year of 2025. *Appl. Mech. Mater.* 409–410:83–88
150. Li JW, Liu ZF, He CY, Yue HB, Gou SY. 2017. Water shortages raised a legitimate concern over the sustainable development of the drylands of northern China: evidence from the water stress index. *Sci. Total Environ.* 590:739–50
151. Dalin C, Hanasaki N, Qiu HG, Mauzerall DL, Rodriguez-Iturbe I. 2014. Water resources transfers through Chinese interprovincial and foreign food trade. *PNAS* 111:9774–79
152. Zhao X, Liu JG, Liu QY, Tillotson MR, Guan DB, Hubacek K. 2015. Physical and virtual water transfers for regional water stress alleviation in China. *PNAS* 112:1031–35
153. Deines JM, Liu X, Liu JG. 2016. Telecoupling in urban water systems: an examination of Beijing's imported water supply. *Water Int.* 41:251–70
154. Liu J, Yang W, Li S. 2016. Framing ecosystem services in the telecoupled Anthropocene. *Front. Ecol. Environ.* 14:27–36
155. Cai BM, Wang CC, Zhang B. 2017. Worse than imagined: unidentified virtual water flows in China. *J. Environ. Manag.* 196:681–91
156. Jiang XJ, Zhang Q, Zhao HY, Geng GN, Peng LQ, et al. 2015. Revealing the hidden health costs embodied in Chinese exports. *Environ. Sci. Technol.* 49:4381–88
157. Guo Je, Zhang Z, Meng L. 2012. China's provincial CO_2 emissions embodied in international and interprovincial trade. *Energy Policy* 42:486–97
158. Lin JT, Pan D, Davis SJ, Zhang Q, He KB, et al. 2014. China's international trade and air pollution in the United States. *PNAS* 111:1736–41
159. Qiu LD, Zhan CQ. 2016. China's global influence: a survey through the lens of international trade. *Pac. Econ. Rev.* 21:45–71
160. Wang C, Zang Z, Qiu Y, Deng S, Feng Z, et al. 2017. The effectiveness of Shennongjia National Nature Reserve in conserving forests and habitat of Sichuan snub-nosed monkey. *Biodivers. Sci.* 25:504–12
161. Lew AA, Li ZF. 2017. China: a growth engine for world tourism. In *Routledge Handbook of Tourism in Asia*, ed. CM Hall, SJ Page, pp. 308–23. New York: Routledge
162. Zhang F, Gallagher KS. 2016. Innovation and technology transfer through global value chains: evidence from China's PV industry. *Energy Policy* 94:191–203
163. Vlassis A. 2016. Soft power, global governance of cultural industries and rising powers: the case of China. *Int. J. Cult. Policy* 22:481–96
164. Han MY, Dunford M, Chen GQ, Liu WD, Li YL, Liu SY. 2017. Global water transfers embodied in Mainland China's foreign trade: production- and consumption-based perspectives. *J. Cleaner Prod.* 161:188–99

165. Zhang Q, Jiang XJ, Tong D, Davis SJ, Zhao HY, et al. 2017. Transboundary health impacts of transported global air pollution and international trade. *Nature* 543:705–9
166. Dumon M. Top 6 factors that drive investment in China. *Investopedia*. **https://www.investopedia.com/articles/economics/09/factors-drive-investment-in-china.asp**
167. Chen W, Dollar D, Tang H. 2016. Why is China investing in Africa? Evidence from the firm level. *World Bank Econ. Rev.* lhw049. **https://doi.org/10.1093/wber/lhw049**
168. Liu Z, Davis SJ, Feng K, Hubacek K, Liang S, et al. 2016. Targeted opportunities to address the climate–trade dilemma in China. *Nat. Clim. Change* 6:201–6
169. Guan D, Hubacek K, Weber CL, Peters GP, Reiner DM. 2008. The drivers of Chinese CO_2 emissions from 1980 to 2030. *Glob. Environ. Change* 18:626–34
170. Weber CL, Peters GP, Guan D, Hubacek K. 2008. The contribution of Chinese exports to climate change. *Energy Policy* 36:3572–77
171. Zhu C, Taylor R, Feng G. 2004. *China's Wood Market, Trade and the Environment*. Monmouth Junction, NJ: Science Press
172. Liu J. 2014. Forest sustainability in China and implications for a telecoupled world. *Asia Pac. Policy Stud.* 1:230–50
173. Ali T, Huang JK, Wang JX, Xie W. 2017. Global footprints of water and land resources through China's food trade. *Glob. Food Secur.* 12:139–45
174. Sun J, Mooney H, Wu W, Tang H, Tong Y, et al. 2018. Importing food damages domestic environment: evidence from global soybean trade. *PNAS* 115:415–19
175. Yeter D, Deth R, Kuo HC. 2015. Are man-made pollutants originating from China, Central Asia one of the indborne mystery infections of Kawasaki disease carried across the Pacific? *Circulation* 131:A30
176. Liu Y, Hu XH, Feng KS. 2017. Economic and environmental implications of raising China's emission standard for thermal power plants: an environmentally extended CGE analysis. *Resour. Conserv. Recycl.* 121:64–72
177. Casanova L. 2018. The challenges of Chinese investment in Latin America. *World Econ. Forum*, March 15. **https://www.weforum.org/agenda/2018/03/latin-america-china-investment-brazil-private-public**
178. Shinn DH. 2016. The Environmental Impact of China's Investment in Africa. *Cornell Int. Law J* 49:25
179. Liu J, Hull V, Batistella M, DeFries R, Dietz T, et al. 2013. Framing sustainability in a telecoupled world. *Ecol. Soc.* 18:26
180. Federal Register. 1998. Policy on giant panda permits. *Fed. Reg.* 63:166. **https://www.gpo.gov/fdsys/pkg/FR-1998-08-27/pdf/98-23074.pdf**
181. Yang D, Cai J, Hull V, Wang K, Tsang YP, Liu J. 2016. New road for telecoupling global prosperity and ecological sustainability. *Ecosyst. Health Sustain.* 2:e01242
182. Xinhua. 2017. Xi leads ecological civilization. *China Daily*, March 22. **http://www.chinadaily.com.cn/china/2017-03/22/content_28634915.htm**
183. Zhou XX, Feng C. 2017. The impact of environmental regulation on fossil energy consumption in China: direct and indirect effects. *J. Cleaner Prod.* 142:3174–83
184. *Xinhuanet.com*. 2017. Long-term, ambitious climate goals boost green finance: China's top climate envoy. *Xinhuanet.com*, Dec. 13. **http://www.xinhuanet.com/english/2017-12/13/c_136820921.htm**
185. State Administration of Taxation of China. 2017. *The environmental protection tax will start on January 1, 2018* (in Chinese). **http://www.chinatax.gov.cn/n810341/n810780/c2949707/content.html**
186. Zhang QT, Xia Q, Liu CCK, Shu G. 2013. Technologies for efficient use of irrigation water and energy in China. *J. Integr. Agr.* 12:1363–70
187. Zeng M, Liu XM, Li YL, Peng LL. 2014. Review of renewable energy investment and financing in China: status, mode, issues and countermeasures. *Renew. Sustain. Energy Rev.* 31:23–37
188. Pan LY, Liu P, Li Z. 2018. A discussion on China's vehicle fuel policy: based on the development route optimization of refining industry. *Energy Policy* 114:403–12
189. Liu C. 2011. Chinese mayors encourage car owners to use public transit instead. *Scientific American*, Febr. 9. **https://www.scientificamerican.com/article/chinese-encourage-car-owners-public-transit**
190. Tan H. 2016. There's another way to solve China's industrial overcapacity. *China Dialogue*, Dec. 21. **https://www.chinadialogue.net/article/show/single/en/9510-There-s-another-way-to-solve-China-s-industrial-overcapacity**

191. Ministry of Environmental Protection of China. 2012. *Notice on Distributing the "Mission Division of the China Action Plan of the Biodiversity Conservation Strategy (2011–2030)" and the "China Action Plan the United Nations Biodiversity Decade"* (in Chinese). Beijing: Minist. Environ. Protect. China. **http://www.mep.gov.cn/gkml/hbb/bwj/201606/t20160601_352974.htm**
192. State Council of the People's Republic of China. 2015. *State Council's Notice on Distributing the Action Plan of Water Pollution Prevention and Control* (in Chinese). Beijing: State Counc. PRC. **http://www.most.gov.cn/yw/201504/t20150416_119031.htm**
193. Cass LR. 2014. Air pollution and acid rain. In *Routledge Handbook of Global Environmental Politics*, ed. PG Harris, pp. 388–99. London: Routledge
194. Yassaa N. 2016. Air pollution may alter efforts to mitigate climate change. *Atmos. Environ.* 127:221–22
195. Tambo E, Wang DQ, Zhou XN. 2016. Tackling air pollution and extreme climate changes in China: implementing the Paris climate change agreement. *Environ. Int.* 95:152–56
196. Liu J, Mooney H, Hull V, Davis SJ, Gaskell J, et al. 2015. Systems integration for global sustainability. *Science* 347:1258832
197. Hou DY, Li FS. 2017. Complexities surrounding China's soil action plan. *Land. Degrad. Dev.* 28:2315–20
198. Geng JJ, Niu XJ, Jin XC, Wang XR, Gu XH, et al. 2005. Simultaneous monitoring of phosphine and of phosphorus species in Taihu Lake sediments and phosphine emission from lake sediments. *Biogeochemistry* 76:283–98
199. Qiu HM, Geng JJ, Ren HQ, Xu ZY. 2016. Phosphite flux at the sediment-water interface in northern Lake Taihu. *Sci. Total Environ.* 543:67–74
200. Han C, Geng JJ, Zhang JA, Wang XR, Gao SX. 2011. Phosphine migration at the water-air interface in Lake Taihu, China. *Chemosphere* 82:935–39
201. Liu J, Hull V, Godfray HCJ, Tilman D, Gleick P, et al. 2018. Nexus approaches to global sustainable development. *Nat. Sustain.* 1:466–76
202. Liu J. 2013. Effects of global household proliferation on ecosystem services. In *Landscape Ecology for Sustainable Environment and Culture*, ed. B Fu, BK Jones, pp. 103–18. Dordrecht: Springer
203. *Xinhua News Agency*. 2018. Explanation of the State Council's Institutional Reform Plan (in Chinese). *Xinhua News Agency*, March 14. **http://www.gov.cn/guowuyuan/2018-03/14/content_5273856.htm**
204. *Beijing Daily*. 2018. Beijing: removing another 500 polluting enterprises this year *(in Chinese)*. *Beijing Daily*, **http://www.gov.cn/xinwen/2018-02/06/content_ 5264213.htm**
205. Yang W, Lu Q. 2018. Integrated evaluation of payments for ecosystem services programs in China: a systematic review. *Ecosyst. Health Sustain.* 4:73–84
206. Wang X, Fu MC. 2016. Coordination of the industrial relocation and the cultural and creative industries in the post-industrial age in Beijing. *Adv. Econ. Bus. Manag. Res.* 10:104–8
207. Liu J, Dietz T, Carpenter S, Alberti M, Folke C, et al. 2007. Complexity of coupled human and natural systems. *Science* 317:1513–16
208. State Forestry Administration of China. 2017. *China Forestry Development Report*. Beijing: China For. Press
209. Liu J, Ouyang Z, Yang W, Xu W, Li S. 2013. Evaluation of ecosystem service policies from biophysical and social perspectives: the case of China. In *Encyclopedia of Biodiversity*, ed. SA Levin, pp. 372–84. Waltham, MA: Academic. 2nd ed.
210. National Bureau of Statistics of China. 2018. *National data* (in Chinese). **http://data.stats.gov.cn/easyquery.htm?cn=C01**
211. Shen J. 2014. *Knowing how to Drink Water, Be Healthy* (in Chinese). Beijing: Petrol. Ind. Press

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