Spatial characteristics of ecological degradation and restoration in China from 2000 to 2015 using remote sensing

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Ecosystem degradation can lead to adverse consequences and disasters and hence a healthy ecosystem is imperative for human well-being. As a country with a large population and area, China’s ecological security has global significance. To determine the effect of existing land use and relevant policies on the ecosystem, we need to understand the current situation of China’s ecological degradation and restoration. However, relevant research at the national scale is lacking. We used remote sensing and GIS methods to study the extent, type, and composition of ecological degradation and restoration in China, at the national scale, from 2000 to 2015. The results revealed that the fundamental cause of China’s ecological degradation was development and construction, and this kind of degradation is difficult to recover from. In the 15 years, the restoration area of this type of ecological degradation accounted for only 11% of the total degraded area. The total area that was newly constructed was 87,961.04 km\textsuperscript{2}, of which 66,176.04 km\textsuperscript{2} was previously cultivated land. For food security, another 75,258.36 km\textsuperscript{2} of cultivated land was reclaimed. The two types of ecological degradation accounted for 71.59% of the total degraded area, and the increasing farmland area alone caused 42.14% of wetland degradation. Existing restoration projects are generally effective, but degradation, especially desertification, in the arid and semiarid regions of the northwest still needs special attention. Above all, ecological protection should be the focus, while ecological restoration the remedy.

\textbf{Key words:} compensation system for cultivated land occupation, development and construction, ecological degradation, ecological restoration, land urbanization, wetland atrophy

\textbf{Implications for Practice}

- Development and construction, directly and indirectly, led to 71.59\% of the ecological degradation in China that can be prevented by implementing an economic intensive urban development model.
- Approximately, 42.14\% of wetland shrinkage was caused by cultivated land reclamation. Wetlands provide the highest service value; hence, they should be protected.
- The cultivated land compensation system ensures that the cultivated area does not decrease, but it reduces the cultivated land quality.
- Although the effect of ecological protection and restoration projects has been positive, differences between the original and secondary vegetation should be considered.
- Bare land and desert require the longest time for ecological recovery. Inner Mongolia, Gansu, and the Southeast hills are, hence, key areas that need protection.

\textbf{Introduction}

Ecosystems including forests, shrubs, grasslands, and wetlands provide many services for human beings (Guan et al. 2018; Bo et al. 2019). In 1997, Costanza et al. (1997) estimated the global minimum annual economic value of 17 ecosystem services as 16–54 trillion U.S. dollars, with an average value of 33 trillion U.S. dollars, while they estimated the global gross national economic output value at approximately 18 trillion U.S. dollars. Thus, the value of ecosystem services is an important component of the global economy. Further, ecosystem services are closely related to our well-being (Yang et al. 2010; Wang et al. 2013; Zheng et al. 2013). The Millennium Ecosystem Assessment (2005) divided ecosystem services into four kinds from the perspective of human demand: provisioning, regulating, supporting, and cultural services. It can be seen that these services cover all aspects...
of human survival. The value of an ecosystem service function is determined by the number of natural assets (Ouyang et al. 2016; Lv 2018a), which in turn is determined by the ecosystem. Ecological degradation and restoration correspond to the loss and increase in natural assets. Therefore, to increase natural assets and improve the value of ecosystem services, ecological degradation must be prevented and ecological restoration should be promoted.

Globally, ecosystem damage leads to many adverse consequences such as global warming causing extreme weather, species extinction, and disease outbreaks (Donohoe 2003). A healthy and stable ecosystem is important for economic development and well-being. Ecological degradation can be the cause of local wars (Suliman 1997), emigration (Ezra 1997, 2001), and loss of livelihood (Pape & Löfler 2012). Further, the loss of areas of high ecological value to mankind is difficult to evaluate once ecological degradation occurs. For example, degradation of the benthic littoral zone in the Baikal Lake, the most species-rich lake on earth can lead to species loss (Timoshkin et al. 2016), which cannot be assessed later. Deforestation and destruction of river basins can result in the loss of biomass and carbon sinks, destroy regional water balance, and negatively impact local climate (Foley et al. 2007). Different types of ecosystems have different functions and cannot be replaced by each other. However, degradation of one ecosystem type may harm the other. For example, there are differences in the species supported by grassland and shrub ecosystems. Degradation reduces the number of plant species in grassland, which in turn triggers dependent herbivores such as prairie dogs to invade and destroy shrub ecosystems (Ceballos et al. 2010). In addition to providing biological support and supplying fish and other ecological products, wetland ecosystems also have sewage purification, flood regulation, and storage functions (Richardson 1994). Degradation of forest ecosystems leads to soil erosion, flooding, damage to irrigation systems, soil salinization, and reduction of agricultural harvest (Bodley 2002; Yu et al. 2009). All of the above indicate the importance of ecosystem protection, and the need to focus on ecological degradation and restoration.

As a large country, both in area and population, China’s ecological security is of great significance. The Chinese government has paid increasing attention to ecological protection (Liu et al. 2018a; He 2018). The focus of research on ecological degradation and restoration in China has mainly been at the small to medium scale, focusing on specific areas such as the Qinghai Tibet Plateau (Cai et al. 2015), Inner Mongolia (Li et al. 2007), the Karst regions of South China (Tong et al. 2017), the source region of the Yangtze and Yellow rivers (Zhou et al. 2005), Sanjiang Plain (Zhou et al. 2009), Shenzhen (Zhou et al. 2011), and nature reserves (Liu et al. 2001). Most studies have concentrated on only a single ecosystem (Zhou et al. 2005; Li et al. 2007; Cai et al. 2015). The research methods mainly include a combination of remote sensing and GIS methods (Zhou et al. 2011; Cai et al. 2015), field investigations (Li et al. 2007), or a combination of the above three methods (Zhou et al. 2009). The subject of these studies mainly includes the effectiveness of ecological engineering (Cai et al. 2015), the status and causes of ecological degradation (Zhou et al. 2005; Zhou et al. 2009), and the relationship between the socio-economy and ecological degradation (Li et al. 2007; Zhou et al. 2011). Research on ecological degradation and restoration at the national scale are mostly review articles (Li 2004; Akiyama & Kawamura 2007) or macro analysis of processes (Akiyama & Kawamura 2007), technology (Li 2004), the legal system (Xu 2019), and policy (Yu 2002; Li 2004), which lack spatial data support. Although some information on ecological degradation and restoration can be extracted from studies on the evolution of spatial patterns of land use, it is far from enough. For example, in the studies by Liu et al. (2003, 2010, 2018b), it is not clear what types of ecosystems the new built-up areas evolved from or what ecosystem type the reduced area of water body changed into. Further, it is difficult to distinguish between ecological degradation and ecological restoration areas. Wang et al. (2001) studied China’s land use spatiotemporal change from 1996 to 2000 but report only the area statistics at the provincial scale. Thus, there is a paucity of studies, at the national scale, on the spatial and temporal evolution of ecological degradation and restoration.

However, to prevent ecological degradation and promote ecological restoration, it is necessary to specify locations with severe ecological degradation, identify the main types of degradation, note any ecological restoration in the area, evaluate if existing ecological restoration projects are practical, and determine areas that need to be focused on. Such information will help determine the current problems in the process of ecological degradation and restoration in China as well as the areas that need to be focused on and improved in the future. In this study, we first analyzed the spatial distribution of the intensity of ecological degradation and restoration and the overall situation in China to determine the status of ecological degradation and restoration in the country, and to ascertain the location of areas with serious ecological degradation. Second, spatial analysis of the types of ecological degradation and restoration in China was undertaken, wherein, based on the spatial distribution of the intensity of ecological degradation and restoration, we determined the specific causes of China’s ecological degradation and restoration. Finally, to clarify the problems existing in the process of ecological degradation and restoration and to identify matters needing attention in the future, we analyzed the spatial composition of ecological degradation and restoration types.

**Methods**

The data on ecosystem classification come from the National Eco-environment Ten Year Change (2000–2010) Remote Sensing Survey and Assessment Project, and the National Eco-environment Five Year Change (2010–2015) Remote Sensing Survey and Assessment Project supported by the Chinese Academy of Sciences and the Ministry of Ecology and Environment (Ouyang et al. 2014). The 2000 and 2015 national land cover datasets at 30 m resolution are from domestic environmental satellites (HJ-1A/B) and U.S. Landsat OLI data. This dataset is supported by a classification sample database constructed from a large number of ground survey sample points, obtained by using object-oriented multi-scale segmentation and decision tree for classification. A strict quality control system was used to
ensure the accuracy of data, and independent data accuracy verification was carried out for the ground survey sample points obtained by a random sampling method to ensure the objectivity and reliability of the accuracy evaluation. In 2015, the data were based on 118,316 independent survey sample points, with an average accuracy of 93.65% for first-level categories. The original ecosystem classification data contained 22 second-level sub-categories and 42 third-level sub-categories (Ouyang et al. 2015). This study reclassified them into eight first-class categories: forests, shrubs, grasslands, wetlands, farmland, towns, deserts, and others (which included glaciers/permanent snow and bare ground) (Table 1).

In this study, forests, shrubs, grasslands, wetlands, and farmland ecosystems were considered to be ecological land, and their ecosystem service function value was ranked: wetland > forest > shrub > grassland > farmland (Xu et al. 2003). The process of transforming an ecological land with higher value ecosystem services into an ecological land with lower value or to a non-ecological land was defined as ecological degradation. Conversely, the process of transforming an ecological land with lower value ecosystem services into one with higher value or a non-ecological land into an ecological land was defined as ecological restoration. According to the most concerning ecological problems in China, ecological degradation was classified into five types: desertification, wetland atrophy, cultivated land reclamation, vegetation degradation, and development and construction. Corresponding to these, five types of ecological restoration were also classified (Fig. 1).

This is a novel method to classify the ecological degradation and restoration. The evolution of land use patterns may involve

Table 1  Ecosystem classification.

| Code | Level I  | Code | Level II       | Code | Level III          |
|------|---------|------|----------------|------|--------------------|
| 1    | Forest  | 11   | Broad-leaved forest | 111  | Broad-leaved evergreen forest |
|      |         | 12   | Coniferous forest  | 112  | Deciduous broad-leaved forest |
|      |         | 13   | Mixed coniferous and broad-leaved forest | 121  | Evergreen coniferous forest |
|      |         | 14   | Sparse forest      | 122  | Deciduous coniferous forest |
| 2    | Shrub   | 21   | Broadleaf irrigation | 131  | Mixed coniferous and broad-leaved forest |
|      |         | 22   | Coniferous irrigation | 141  | Sparse forest |
|      |         | 23   | Sparse irrigation  | 211  | Evergreen broad-leaved shrub forest |
| 3    | Grassland | 31   | Meadow           | 212  | Deciduous broad-leaved shrub forest |
|      |         | 32   | Grassland        | 221  | Evergreen coniferous shrub forest |
|      |         | 33   | Thick growth of grass | 231  | Sparse shrubbery |
|      |         | 34   | Sparse grassland  | 311  | Meadow |
|      |         |      |                 | 321  | Grassland |
|      |         |      |                 | 331  | Thick growth of grass |
|      |         |      |                 | 341  | Sparse grassland |
| 4    | Wetland | 41   | Swamp           | 411  | Forest swamp |
|      |         | 42   | Lake            | 412  | Shrub swamp |
|      |         | 43   | Rivers          | 413  | Herbaceous swamp |
|      |         |      |                 | 421  | Lake |
|      |         |      |                 | 422  | Reservoir/pond |
|      |         |      |                 | 431  | Rivers |
|      |         |      |                 | 432  | Canal/canal |
| 5    | Farmland | 51   | Cultivated land | 511  | Paddy field |
|      |         | 52   | Garden plot     | 512  | Dry land |
|      |         |      |                 | 521  | Arbor garden |
|      |         |      |                 | 522  | Shrubby garden |
| 6    | Urban   | 61   | Place of residence | 523  | Shrubs |
|      |         | 62   | City green space | 524  | Herbaceous green space |
|      |         |      |                 | 611  | Place of residence |
|      |         |      |                 | 621  | Arbor green space |
|      |         |      |                 | 622  | Shrubs |
|      |         |      |                 | 631  | Industrial land |
|      |         |      |                 | 632  | Traffic land |
|      |         |      |                 | 633  | Mining ground |
| 7    | Desert  | 71   | Desert          | 711  | Desert |
| 8    | Others  | 81   | Glacier/permanent snow | 712  | Desert bare rock |
|      |         | 82   | Bare land       | 713  | Desert bare soil |
|      |         |      |                 | 714  | Desert saline alkali land |
|      |         |      |                 | 811  | Glacier/permanent snow |
|      |         |      |                 | 821  | Moss/lichen |
|      |         |      |                 | 822  | Bare rock |
|      |         |      |                 | 823  | Bare soil |
|      |         |      |                 | 824  | Saline alkali soil |
|      |         |      |                 | 825  | Sand |
several types of local ecological degradation and restoration. However, few studies have included all land use pattern changes into the scope of ecological degradation and restoration, which could provide a more comprehensive and clear assessment of ecological changes. The biggest problem for classifying ecological degradation and restoration types is that a certain ecosystem change may result from more than one type of ecological degradation, which could result in the area being included multiple times leading to erroneous area calculations. To address this problem and answer the question, which type of ecosystem change should be classified for which type of ecological degradation and restoration, in this study we considered ecological degradation as the focus of the classification, because the prevention and control of ecological degradation are more significant to human beings. Thus, we classified ecosystem change as the type of ecological degradation that has a greater impact and is of more concern.

This study used the ArcGIS 10.3 platform for data analysis and processing. Given China’s vast land area, data at 30 m resolution was too large, affecting the data processing speed. Hence, we resampled the data to 90 m resolution. Taiwan Province was not included in the analysis. The study area was grided, and data on land cover type was summarized for each grid for 2000 and 2015. From these, changes in the land cover type were determined (Fig. 2A). Gridwise ecological degradation and ecological restoration (Fig. 2B) were identified and extracted. These were reclassified into two sets of data: one classified the ecological degradation and restoration into broad categories (Fig. 2C), while the other classified the data into five, more detailed, categories (Fig. 2D) according to the classification method shown in Figure 1. Then, we used the fishnet tool in ArcGIS to create a 10 km × 10 km fishing net (Fig. 2E), and taking this as the basis for regional division, we determined zonal-level statistics for the national ecological degradation/restoration data shown in Figure 2C, and obtained the number of grids that showed ecological degradation or restoration in each 10 km × 10 km grid. We then carried out grid calculation according to Formula (1) to determine the ecosystem conversion rate the results of which are shown in Figure 3. The ecosystem offset conversion rate was calculated according to Formula (2), where the grid calculations from the previous step were used and the results are shown in Figure 4. According to the data on national ecological degradation and restoration (Fig. 2C), the number of grids for ecological degradation and restoration in each provincial administrative region was obtained. Based on this, the area of ecological degradation and restoration in each provincial administrative region was calculated using Formula (3). Then, using Formula (4), the overall ecological situation of each provincial administrative region in the country was calculated (Fig. 5). Finally, we used the tabulate area tool in ArcGIS to calculate the statistics of the grid data of ecosystem degradation and restoration (Fig. 2B & 2D) and obtained the area of ecosystem degradation and restoration (Table 2).

Ecosystem conversion rate = \( \frac{X \times 90 \text{ m} \times 90 \text{ m}}{1,000,000} \times 10 \text{ km} \times 10 \text{ km} \times 100\% \)
Ecosystem offset conversion rate
= Degradation conversion rate – Restoration conversion rate

Ecosystem conversion area = \( rac{90 \text{ m} \times 90 \text{ m} \times \text{Number of grids}}{1,000,000} \)

Ecosystem offset conversion area
= Degraded ecosystem area – Restored ecosystem area

Results

Distribution of Ecological Degradation and Restoration in China

From 2000 to 2015, the total area that was ecologically degraded in China was 227,989.42 km\(^2\), and the total ecological restoration area was 162,753.63 km\(^2\), which indicated that the overall ecological situation in China was in the negative. The regions with serious ecological degradation in China were mainly distributed in the Inner Mongolia Autonomous Region; the Tarim
Basin around Tian Shan Mountains, Erquis River Basin, and periphery of Wulungu Lake in the Xinjiang Uygur Autonomous Region; in the Hexi Corridor and Shule River Basin in Gansu Province; in parts of the Northeast Plain and Sanjiang Plain in Heilongjiang Province; in the Beijing-Tianjin-Hebei Region; and in the Yangtze River and Pearl River deltas. Almost all of the North China Plain, the middle and lower reaches of the Yangtze River Plain, and the Southeast Hilly Areas suffered serious ecological degradation, especially in the eastern coastal areas. The most obvious areas that had undergone ecological restoration in China were also mainly located in the Inner Mongolia Autonomous Region, followed by the Loess Plateau area, including Longdong, Ningxia Hui Autonomous Region, and Northern Shaanxi. In addition, ecological restoration was also seen in the western Wushan Mountains in Hubei Province, Guizhou Province, the southern part of Hunan Province, and parts of the southeastern coastal areas (Fig. 3).

Based on our results on the offset between ecological degradation and restoration in China (Fig. 4), the regions with the most significant ecological degradation were mainly located in the Xinjiang Uygur Autonomous Region, the northeast corner of Heilongjiang Province, the whole North China Plain, the middle and lower reaches of the Yangtze River, the southeast coastal areas, especially the Yangtze River and Pearl River deltas, and the provincial capitals. The areas with the best ecological restoration were mainly located at the junction of Shaanxi, Gansu, and Ningxia and in the Guizhou Province. By ranking the ecological status of the 33 provinces based on the ecosystem offset conversion area, we found that in only seven provinces, the degraded ecosystem area was offset by the restored ecosystem area (Fig. 5).
Table 2: Ecological degradation and restoration in China from 2000 to 2015.

| Development and construction | Total | Ecological Degradation | | Ecological Restoration | Difference/ km² |
|-----------------------------|-------|------------------------|--------------------------|----------------|-------------------|
| Farmland → Urban | 66,176.04 | 29.03 | 78.53 | Recovery | Urban → Farmland | 5,116.99 | 3.14 | 58.83 | — |
| Grassland → Urban | 9,865.69 | 4.33 | 11.71 | — | Urban → Grassland | 2,557.15 | 1.57 | 29.4 | — |
| Forest → Urban | 5,536.12 | 2.43 | 6.57 | — | Urban → Forest | 700.62 | 0.43 | 8.05 | — |
| Shrub → Urban | 2,687.44 | 1.18 | 3.19 | — | Urban → Shrub | 323.64 | 0.2 | 3.72 | — |
| Total | 84,265.29 | 36.96 | — | — | Total | 8,698.39 | 5.34 | — | — |

| Cultivated land reclamation | Total | — | — | — | — | — |
| Grassland → Farmland | 36,183.27 | 15.87 | 58.62 | Returning farmland to forest and grassland | Farmland → Grassland | 31,270.3 | 19.21 | 50.82 | — |
| Shrub → Farmland | 13,435.04 | 5.89 | 21.77 | — | Farmland → Forest | 21,320.5 | 13.1 | 34.65 | — |
| Forest → Farmland | 12,106.55 | 5.31 | 19.61 | — | Farmland → Shrub | 8,939.1 | 5.49 | 14.53 | — |
| Total | 61,724.86 | 27.07 | — | — | Total | 61,529.9 | 37.81 | — | — |

| Wetland atrophy | Total | — | — | — | — |
| Grassland → Wetland | 13,533.5 | 5.94 | 42.14 | — | Wetland → Grassland | 9,966.23 | 6.12 | 29.75 | — |
| Wetland → Grassland | 6,122.51 | 2.69 | 19.06 | — | Wetland → Desert | 5,574.57 | 3.43 | 16.64 | — |
| Wetland → Desert | 3,655.75 | 1.62 | 11.51 | — | Wetland → Shrub | 4,699.23 | 2.89 | 14.03 | — |
| Wetland → Shrub | 3,655.07 | 1.6 | 11.35 | — | Wetland → Urban | 1,065.7 | 0.65 | 3.18 | — |
| Wetland → Others | 13.77 | 0.01 | 0.04 | — | Wetland → Others | 64.65 | 0.04 | 0.19 | — |
| Total | 32,118.85 | 14.09 | — | — | Total | 33,495.93 | 20.58 | 194.96 | — |

| Vegetation degradation | Total | — | — | — | — |
| Shrub → Grassland | 9,407.47 | 4.13 | 33.36 | — | Grassland → Forest | 12,525.69 | 7.7 | 36.23 | — |
| Forest → Grassland | 8,819.38 | 3.87 | 31.28 | — | Grassland → Shrub | 10,030.48 | 6.16 | 29.01 | — |
| Forest → Shrub | 8,419.04 | 3.69 | 29.86 | — | Shrub → Forest | 9,849.24 | 6.05 | 28.49 | — |
| Grassland → Others | 1,495.16 | 0.66 | 5.3 | — | Others → Grassland | 1,311.24 | 0.81 | 3.79 | — |
| Shrub → Others | 52.51 | 0.02 | 0.19 | — | Others → Shrub | 758.49 | 0.47 | 2.19 | — |
| Forest → Others | 4.84 | 0 | 0.02 | — | Others → Forest | 96.43 | 0.06 | 0.28 | — |
| Total | 28,198.39 | 12.37 | — | — | Total | 34,571.58 | 21.24 | 1,377.08 | — |

| Desertification | Total | — | — | — | — |
| Grassland → Desert | 15,259.65 | 6.69 | 70.38 | — | Desert → Grassland | 17,582.96 | 10.8 | 71.89 | — |
| Forest → Desert | 2,579.13 | 1.13 | 11.9 | — | Desert → Farmland | 3,574.68 | 2.2 | 14.62 | — |
| Shrub → Desert | 1,968.14 | 0.86 | 9.08 | — | Desert → Shrub | 2,111.99 | 1.3 | 8.64 | — |
| Farmland → Desert | 1875.12 | 0.82 | 8.65 | — | Shrub → Forest | 1,188.21 | 0.73 | 4.86 | — |
| Total | 21,682.03 | 9.51 | — | — | Total | 24,457.83 | 15.03 | 6,373.18 | — |

| Total | 227,989.42 | — | — | — | — | 162,753.63 | — | 65,235.8 | — |
Distribution of Ecological Degradation and Restoration Types in China

The leading cause of ecological degradation in the Xinjiang Uygur Autonomous Region was cultivated land reclamation, followed by development and construction, and wetland shrinkage. In the southeastern coastal areas and the central areas of China, especially the Beijing-Tianjin-Hebei Region, the Yangtze River and the Pearl River Delta, and the provincial capitals, ecological degradation was mainly caused by development and construction. Vegetation degradation was the main cause of ecological degradation in the western part of the Wushan Mountains in Hubei Province and the middle section of the Taizhong Mountains at the border between Shanxi Province and Hebei Province. Further, ecological degradation caused by cultivated land reclamation in southeastern Fujian Province and some areas along the border between Fujian Province and Jiangsu Province were evident (Fig. 6). The ecological degradation caused by wetland shrinkage was most significant in the Tibet Autonomous Region, Qinghai Province, and Northeast China, especially in Heilongjiang Province and Jilin Province. The ecological degradation in the Inner Mongolia Autonomous Region had several causes and was the most complex. In general, large areas of wetland shrinking were seen in the northeast, cultivated land reclamation in the east, vegetation degradation in the south, desertification in the northwestern and western areas, and the types of ecological degradation was varied in southwestern of the central area. In addition, the ecological degradation caused by cultivated land reclamation in the southernmost part of Yunnan Province was noticeable (Fig. 6).

The main form of ecological restoration in the western region, the northeast region, the Yangtze River Basin, and the Pearl River Delta region was wetland restoration. The ecological restoration area resulting from converting farmland to forestry and grassland was the second largest, especially at the eastern and southern margins of the Inner Mongolia Autonomous Region, the eastern end of Qinghai Province, Shaanxi-Gansu-Ningxia junction region, western and northern parts of Shanxi Province, the Beijing-Tianjin-Hebei region, the eastern part of Heilongjiang-Jilin-Liaoning Province, west of the Wushan Mountains in the Hubei Province, Guizhou Province, and Jiangsu Province. The third largest area was the vegetation restoration area. These areas were mainly distributed in the Xinjiang Uygur Autonomous Region, western Gansu Province, southwestern Yunnan Province, northern Hebei Province, and a belt running through Inner Mongolia from southwest to northeast. The areas of desert restoration were mainly located in the Xinjiang Uygur Autonomous Region, western part of the border between Heilongjiang Province and Jilin Province, and parts of Guangdong Province, Jiangsu Province, and Zhejiang Province. The area converted from construction land to ecological land in China was very small and scattered (Fig. 6).

Composition of the Ecological Degradation and Restoration Types in China

Development and construction were the main causes of ecological degradation in China, accounting for 36.96% of the total ecological degradation area. Cultivated land reclamation was the second major cause, accounting for 27.07% of the total ecological degradation area. These two factors accounted for 64.03% of the entire ecological degradation area. These two factors accounted for 64.03% of the entire ecological degradation area. Most of the ecological degradation caused by development and construction in China was transformed from farmland (78.53%) and grassland (11.71%). The ecological degradation caused by cultivated land reclamation was mainly because of the conversion of forests, shrublands, and grasslands, and grassland converted to farmland accounted for 58.62% of the cultivated land. The degradation caused by construction and reclamation is considerably more than the restoration of construction land and farmland to ecological land. The area from construction land to ecological land accounted for 10.32% of the new construction land in the same period. The total area of farmland returned to forestry

Figure 6 Distribution map of eco-degradation and eco-restoration types in China.
and grassland in China was 61,529.9 km², of which 50.82% was restored to grasslands, 34.65% to forests, and 14.53% to shrubs. This was only 0.32% less than the area of cultivated land reclamations (Table 2).

Wetland atrophy was the third most dangerous type of ecological degradation in China. Its total area was 32,118.85 km², accounting for 14.09% of the total ecological degradation area. The conversion of wetlands to farmland was the most significant cause of wetland atrophy, accounting for 42.14% of the total wetland atrophy area, followed by wetland degradation to grassland and forest, accounting for 19.06 and 14.04% of the total wetland atrophy area, respectively. Conversions of land for development and construction and to deserts are the other causes of wetland atrophy, accounting for 11.51 and 11.35% of the total wetland atrophy area, respectively. Correspondingly, the wetland restoration area over the same period totaled 33,495.93 km². Overall, the recovery rate for wetland ecosystems over this period was faster than the degradation rate. The newly added area of wetlands was 1,377.08 km², accounting for 4.29% of the wetland degradation area over the same period (Table 2).

Over the 15 years, the total area of vegetation degradation in China was 28,198.39 km², accounting for 12.37% of the total ecological degradation area. The forest degraded area, shrub degraded area, and grassland degraded area accounted for 61.15, 33.55, and 5.3% of the total vegetation degraded area, respectively. During this period, the vegetation restoration area in China was 34,571.58 km², which was 1.23 times larger than the vegetation degradation area. The restoration rates for forest, shrub, and grassland were 1.3, 1.14, and 0.88 times the corresponding degradation rates over the same period, respectively. This shows that, except for the degradation of grasslands, the forest and shrub ecosystems were recovering well (Table 2).

From 2000 to 2015, the desertification area was 21,682.03 km², accounting for 9.51% of the total ecological degradation area. Grassland desertification accounted for 70.38% of the total desertification area, followed by forest, shrub, and farmland desertification, which accounted for 11.9, 9.08, and 8.65%, respectively. The area of desert restoration to forest, shrub, grassland, and farmland was 24,457.83 km², which was 1.13 times that of desertification. The speed of desert restoration to farmland, grassland, and shrub was 1.91, 1.15, and 1.07 times higher than the desertification of the corresponding ecosystems, respectively. Only the rate of desert restoration to forests was less than half that of forest desertification (0.46 times) (Table 2).

**Discussion**

**The Profound and Long-Term Impacts of Development and Construction on Ecological Degradation and Restoration**

Between 2000 and 2015, the total ecological degradation (including wetland shrinkage) caused by development and construction was 87,961.04 km², of which the occupied area of farmland reached 66,176.04 km², accounting for 75.23% of the total area. To ensure food security, China has implemented a system of compensation for occupying cultivated land (Chen et al. 2010; Bo 2017). Thus, another 75,258.36 km² of ecological land (including the occupation of wetlands) was reclaimed in the same period. If cultivated land reclamation was regarded as the indirect impact caused by development and construction, the total area of ecological degradation caused by development and construction was 163,219.4 km², accounting for 71.59% of the total area of degradation (Fig. 7). This showed that development and construction were the most important and fundamental causes of ecological degradation in China. At the same time, the area converted from development and construction to ecological land was 9,675.82 km², accounting for only 11% of the area from ecological land to development and construction. The areas that were converted from construction land to ecological land were mainly industrial and mining land. Thus, the probability that ecological degradation caused by development and construction will be reversed is very small, and its impact is longterm. However, the current rate of land urbanization development in China is fast (Ye 2014; Li & Hu 2016) and is...
a serious waste of land resources (Li & Li 2015; Zhang 2016). The ecological degradation caused by land urbanization should be controlled. China’s land urbanization development model should be transformed into intensive and economic urbanization development model (Fu 2014; Sun et al. 2015), from “incremental expansion” to “stock optimization” (Qian & Zhou 2018), and the concepts of “compact city” (Lv & Qi 2008; Kostas 2018; Martina et al. 2019) and “smart growth” (Guan & Zhang 2017; Li et al. 2018) should be considered.

Guard Against the Trap of the Compensation System for Occupying Cultivated Land

In the past 15 years, farmland converted for development and construction in China was mainly distributed in areas with better water and temperature conditions, which were in the east and south. However, after the implementation of the compensation system for occupied farmland, the newly reclaimed farmland was mainly distributed in the Inner Mongolia Autonomous Region and the Xinjiang Uygur Autonomous Region. The water and heat conditions in these areas were worse than the former, which resulted in a decline in farmland quality. This showed that the compensation system of occupying cultivated land to a large extent resulted in a decline in the quality of arable land. To save economic costs, regions with relatively backward economic development levels are generally selected for cultivated land reclamation, which results in the aggravation of local ecological degradation, and this may lead to a vicious circle of economic and ecological poverty. One more thing that needs special attention is that 42.14% of the wetland shrinkage was caused by cultivated land reclamation over the 15 years. Wetlands have some essential ecosystem service functions that other ecosystems lack, and play an irreplaceable role in biodiversity, flood regulation, and storage (Joy & Suzanne 2005; Valentina et al. 2008; Holland et al. 2012; Daniel & Matthew 2013). Hence, the protection of wetlands should be a focus. Thus, there are some potential problems in the compensation system of cultivated land occupation although it is beneficial for the national food security. The fundamental solution is to improve the efficiency of urban land use and control extensive land urbanization. Furthermore, the red line for ecological protection (Meng et al. 2015) and for permanent basic farmland protection (Ma 2018) should be delimited and strictly observed to try and protect high-quality ecological land and good farmland from being exploited and utilized. Furthermore, the practice of “multi-planning integration” should be followed during the process of land urbanization to optimize the spatial layout and effectively allocate land resources (Su & Chen 2015; Yan et al. 2017).

Hidden Dangers Behind the Effectiveness of Ecological Restoration Projects

According to the results of this study, although the degradation caused by development and construction is hard to recover from, the restoration of other types of ecological degradation is relatively achievable. In particular, the restoration areas of wetlands, vegetation, and deserts have exceeded the corresponding degradation areas. This shows that the current ecological restoration projects implemented in China, such as returning farmland to forests and grasslands (Liu et al. 2018c), the Three North Shelterbelt Project (Chen et al. 2015; Zhou 2017), and the Natural Forest Protection Project (Lin et al. 2018; Xiao et al. 2018) have had remarkable effects for ecological restoration. However, when the ecological restoration area offsets (or more than offsets) the ecological degradation area, does it mean that the negative impact of ecological degradation has been reduced? It has been found that the species diversity of the natural ecosystem is more abundant, which can provide higher productivity and more stability (Flombaum & Sala 2008), implying that if we rely on ecological restoration projects for the management and control and reduction of ecological degradation, it will lead to the continuous loss of natural ecosystems. It has also been proposed that the establishment of artificial forests has a significant effect on species diversity (Bremer & Farley 2010). This study suggests that while recognizing the achievements of ecological projects and continuing to promote them (Environmental Protection Bureau of Qianjiang District 2016; Zhang 2018; Lv 2018b), people should strengthen the supervision of ecological protection and further optimize the methods and technical means of ecological restoration as well as relevant laws, regulations, and policies.

Types and Regions of Ecological Degradation to Be Focused on

In addition to development and construction, there are two ecological processes whose degradation speed is faster than their recovery speed, which is grassland degradation to bare land and forest degradation to desert. The speed of conversion of grassland to bare land was 1.14 times that of bare land to grassland, and the speed of conversion of forest to desert was more than twice that if forest to desert. This suggests that ecological restoration of bare land and desert is more difficult than that of other types of ecological land (Li et al. 2014; Zhang et al. 2015). This is because the vegetation succession generally follows the process from low-level to high-level structural complexity (Zhao 2003). The results of the restoration of deserts in this study also confirmed this view (Table 2). Therefore, restoration of more complex structures, such as forests, is more difficult, time consuming, and requires greater experience. Furthermore, the reason for the easier transformation of deserts into farmland is that the farmland ecosystem was the most human-controlled.

Areas with the more serious degrees of ecological degradation are mainly located in arid and semiarid regions such as the Inner Mongolia Autonomous Region, Hexi Corridor, and the north of Hebei Province, which are areas that are most in danger of desertification. In addition to human factors, climate change is an important cause of ecological degradation in these areas (Li et al. 2003; Bai et al. 2006). Thus, for the ecological restoration of these areas we need to deal with both natural and anthropogenic causes, making such restoration the necessary focus while being difficult to deal with.
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