Identifying ecologically valuable and sensitive areas: a case study analysis from China

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A B S T R A C T
The expansion of artificial constructs with the rapid economic development in China has led to ecological and environmental emergencies. The extent of the decline in natural resources and environmental conditions has recently been recognized. Identifying “ecological protection redlines”, i.e. ecological limits, to guarantee ecological baselines for natural resources and ecosystem service functions would therefore help to coordinate economic development and to protect ecological resources in the coming years. We used remotely sensed and climatic data to delimit the ecological protection redlines for Zibo, a typical and important city in Shandong province, as an example to illustrate the principles and methodology of ecological protection redlines. The area of the ecological protection redlines for Zibo encompassed 1132.26 km², accounting for 18.98% of the total area of Zibo, were mainly distributed in the southern regions of the municipality, and consisted of extremely important areas of ecosystem service functions, including water conservation, both soil and water conservation, windbreaks and sand fixation, and the conservation of biodiversity. This area is extremely sensitive, and development is forbidden. Strict measures of management and control should be implemented to protect the long-term effectiveness of ecological protection redlines.

1. Introduction

Environmental and resource problems have become serious challenges in developing countries (Barbier & Hochard, 2016; López-Angarita, Roberts, Tilley, Hawkins, & Cooke, 2016; Matschullat, 2014). China has been under growing pressure in recent years to protect the environment and its resources as the economy grows and urban construction rapidly expands. National-level policies have thus been adopted by the Chinese government to ensure the sustainable provision of ecosystem services, including programs such as the Natural Forest Protection Program, Sloping Land Conversion Program, Desertification Combating Program round Beijing and Tianjin, Shelterbelt Network Development Program, Wildlife Conservation and Nature Reserve Protection Program, and Industrial Timberland Plantation Program, that aim to protect forests and grasslands to reduce the risk of natural disasters and to restore China’s degraded ecosystems (Wang, Wang, Zhang, Lu, & Ren, 2015; Yin, 2009; Xi et al., 2014).

These policies have improved ecosystem services in recent years (FAO, 2010; MEP, 2007; SFA, 2009), but the challenges of environmental problems and dwindling natural resources remain (Fu, Zhuang, Jiang, Shi, & Lü, 2007; Xi, Bi, & He, 2012). The first China Ecosystem Assessment, which included all of mainland China from 2000 to 2010, reported that most of the ecosystem services evaluated increased during this period, suggesting that China’s national conservation policies contributed substantially to the increase in ecosystem services such as carbon sequestration, soil retention, sand fixation, and water retention (Ouyang et al., 2016). The assessment, however, also found that the ecosystem service of habitat provision decreased by 3.1% in the decade (Ouyang et al., 2016) and that services decreased in some regions affected by few or no policies. Major environmental problems still plague China, e.g. air pollution (especially fog and hazy weather), water shortages and contamination, soil pollution, and lack of conservation of biodiversity (Guo, Guo, Fang, & Zhu, 2015; Sherwood, 2013; Yao, 2016; Yu, 2010), which the Chinese government has considered as key elements of environmental protection (The State Council of China, 2013, 2015, 2016).

The programs for the protection of the environment and its resources, however, focus on increased investment in afforestation on local scopes rather than the country as a whole. These measures have improved the degraded resources and environment to some extent but have not satisfied the pressing global demands of resource and environmental protection with the crises of ecosystem degeneration and...
decoding biodiversity. Nationwide programs have been implemented to “draw a line” for delimiting areas where economic development needed to be coordinated with ecological and resource protection. These “redlines” were first established to protect cropland and forest, but new redlines are needed to safeguard China’s vast biodiversity, environmental resources, and ecosystem services (Sang & Axmacher, 2016). To guarantee the baselines of regional and national security, regional boundary control lines were demarcated in some areas of key ecological function and in sensitive and fragile eco-environments, called “ecological protection redlines” (EPRs).

EPRs refer to areas that have special important functions of ecological spaces and are strictly protected. They are the baselines and lifelines for protecting and maintaining national ecological security, usually including areas with important ecological functions of soil and/ or water conservation, maintenance of biodiversity, wind protection, sand fixation, coastal ecological stabilization, ecological protection of areas vulnerable to soil erosion or land desertification, prevention of rocky desertification, and soil desalination (CGP, 2017a, 2017b). They can be defined as the ecological baseline areas needed to provide ecosystem services for guaranteeing and maintaining ecological, environmental, and biological safety (Bai et al., 2016). EPRs can be used as key areas for coordinated and improved ecological and environmental conservation by the Ministry of Environmental Protection and local governments (Lü, Ma, Zhang, Fu, & Gao, 2013).

An EPR is a systemic innovation of ecological environmental protection in China and is also a system of integrated management. It can be a spatial, areal, or managerial redline, encompassing the entire process of management from pattern to structure and then to the functional protection of ecosystems. An EPR is a baseline of ecological security and a risk line for managing ecosystems. The delineation of ecological protection redlines is therefore both a scientific and a management issue. The demarcation of EPRs for ecological and environmental management will facilitate institutional innovation for establishing an integrative system of ecosystem and environmental management in China (He, Yang, Guo, & Zhao, 2014; Rao, Zhang, & Mou, 2012).

The Chinese government defined the EPRs in 2011 and integrated them into the Environmental Protection Law (SCNPC, 2014). Some new EPRs are currently being established (Ma, Ma, Cai, & Nian, 2015; Si, Li, Zhang, Liang, & Sun, 2013; Wang, Sun et al., 2015; Wang, Wang et al., 2015). EPRs in the Beijing-Tianjin-Hebei region and the provinces (municipalities) along the Yangtze Economic Zone should be established by the end of 2017, EPRs in other provinces, autonomous regions, and municipalities should be established by the end of 2018, and the identification, demarcation, and calibration of the EPRs should be complete by the end of 2020 (Xinhua, 2017). EPRs will be established on a national scale, which is important for the protection of Chinese resources and environments during subsequent actions.

This study identified the EPRs for the city of Zibo in Shandong province, China, using ArcGIS 10.0 (ESRI) (http://www.esrichina.com.cn/softwareproduct/EL/), a platform for analyzing geographic information. Our objectives were to: (1) present the principles and methodology for delimiting EPRs, (2) delimit the EPRs in Zibo, and (3) discuss the challenges of EPR delimitation.

2. Materials and methods

2.1. Study area

The study area (35°55′20″–37°17′14″N, 117°32′15″–118°31′00″E) is in Shandong province, eastern China, in the lower reaches of the Yellow River, and includes five districts and three counties (Fig. 1). The total area is 5965 km², accounting for approximately 3.80% of the area of Shandong. The semi-humid and semi-arid continental climate of this temperate area has four distinct seasons. The mean annual temperature is 12.5–14.2 °C, and mean annual rainfall is 629.5 mm. Mountains, hills, and plains account for approximately 42.0, 29.9, and 28.1% of the area of Zibo, respectively. Zibo, an important industrial city in Shandong province and China, is rich in mineral resources. The annual regional gross domestic product was 400 000 million Yuan in 2014, 7.4% higher than the previous year. The gap between the supply and demand of resources, however, is growing due to extensive industrial production.

2.2. EPR classification and data collection

EPRs delimit the following important classified areas of national and regional ecological security (MEP, 2015).

(1) Areas with important ecological functions: areas where ecosystems are degraded but are very important to national or regional ecological security. These areas are needed to maintain and improve the ability to supply ecological products by limiting large-scale and intensive development of industry and urbanization. They contain areas for water conservation, soil conservation, windbreaks and sand fixation, and biodiversity conservation.

(2) Ecologically sensitive areas: areas that are especially susceptible to interference and environmental change or to the effects of potential natural disasters, which can have negative ecological effects due to improper developmental activities.

(3) Areas where development is forbidden: areas where natural and human resources are protected at various levels where other ecological functions need protection, and where development of industry and urbanization is prohibited.

We used land-use data, a digital elevation model, climatic data, and the normalized difference vegetation index (NDVI) (http://ladweb.nascom.nasa.gov/data/search.html) to evaluate the ecological importance and sensitivity of the study area using a geographic information system (ArcGIS 10.0) (ESRI) and the matrix laboratory, MATLAB (MathWorks). The data for areas where development is forbidden, land-use data, and remotely sensed data were provided by the local authorities, including the forestry, agriculture, territorial resources, environmental protection, building, and water conservancy departments in Zibo. These data were entered into the ArcGIS environment for visualizing images.

2.3. General principles for EPR identification

The delimitation of EPRs should obey the principles of natural, ecological, economic, and social development. Key areas associated with ecosystem compositions and functions are scientifically estimated and discriminated. The area and implementation of EPRs should be assured and combined with the feasibility of the local situation of development and management. As an overall requirement for economic and social development and ecological environmental protection, EPRs must be in accordance with existing plans, such as planning principal functional districts, ecological-function areas, and land uses, which would reserve appropriate space for both development and environmental capacity. EPRs are mandated by the laws of environmental protection, prescribing that EPRs should be delimited and under rigid protection in the areas of key ecological function for national and regional ecological security, ecologically and environmentally sensitive areas, and other important ecological areas (SCNPC, 2014). The delimitation of EPRs is a dynamic process. As productivity and the capacity for ecological protection increase, EPRs can be optimized and adjusted to incrementally increase their scope (MEP, 2015).

2.4. Method of EPR identification

2.4.1. Identification of key ecological-function zones

EPRs emphasize relative importance, so the areas of key ecological
function are estimated by evaluating the ecosystem service functions of special units. Net primary production (NPP) is an important indicator of health and the supply of ecosystem services (Ingraham & Foster, 2008; Taelman, Schaubroeck, Meester, Boone, & Dewulf, 2016; Wang et al., 2014). Assessing the degree of importance of ecosystem services using the NPP quantitative index is convenient and efficient and is simpler than identifying the areas with fewer parameters (Paula & Oscar, 2012).

The NPP was obtained using the Carnegie-Ames-Stanford Approach (CASA) model, which correlates plant productivity with the amount of photosynthetically active radiation absorbed or intercepted by green foliage (Monteith and Moss, 1977; Potter et al., 1993). The CASA equations we used were:

\[ NPP(x,t) = \text{APAR}(x,t) \times \varepsilon(x,t) \]  

\[ \text{APAR}(x,t) = \text{FPAR}(x,t) \times \text{PAR}(x,t) \]  

\[ \varepsilon(x,t) = \varepsilon_{\text{max}} \times T_{\varepsilon 1}(x,t) \times T_{\varepsilon 2}(x,t) \times W_{\varepsilon}(x,t) \]

where \( \text{APAR} \) is absorbed photosynthetically active radiation (mJ m\(^{-2}\)), \( \varepsilon \) is the actual light-use efficiency of the vegetation (g mJ\(^{-1}\)), \( x \) and \( t \) are location and time, respectively, \( \text{PAR} \) is the total incident photosynthetically active radiation (mJ m\(^{-2}\)), \( \text{FPAR} \) is the fraction of \( \text{PAR} \) absorbed by the vegetation canopy, \( \varepsilon_{\text{max}} \) is the maximum light-use efficiency under ideal conditions (g mJ\(^{-1}\)), \( T_{\varepsilon 1} \) and \( T_{\varepsilon 2} \) are the stress effects of low and high temperatures, respectively, on the use efficiency of light energy, and \( W_{\varepsilon} \) is the coefficient for the influence of water stress, which represents the influence of moisture conditions.

Remotely sensed data can provide information for many parameters of the vegetation. We obtained \( \text{FPAR} \) required for calculating NPP from time-series data for the NDVI from the MODIS spectroradiometer aboard the EOS satellites. The climatic data, including total solar radiation, average temperature, and duration of sunshine, were obtained from 122 radiation stations and 756 ground-based meteorological and automatic stations in China (Wang et al., 2014).

The ecosystem services, including water conservation, both soil and water conservation, windbreaks and sand fixation, and biodiversity conservation were evaluated by the following methods.

(1) Evaluation of the importance of the function of water conservation

The formula used for calculating the importance of water conservation was:

\[ S_{\text{wc}} = NPP_{\text{mean}} \times F_{\text{sic}} \times F_{\text{pre}} \times (1-F_{\text{sl}}) \]  

where \( S_{\text{wc}} \) is the service-capability index of water conservation of an ecosystem, \( NPP_{\text{mean}} \) is the average NPP of an ecosystem of a region over many years, \( F_{\text{sl}} \) is a raster-map factor evaluating regional slope based on the maximum and minimum values normalized between 0 and 1 (using geographic information system software and calculated by the digital elevation model), \( F_{\text{sic}} \) is a soil-infiltration factor obtained by equal assignment between 0 and 1 depending on soil texture from clayey to sandy soil, where sandy soil is 1, and \( F_{\text{pre}} \) is a factor for average annual precipitation data interpolated from many years (> 30) and normalized between 0 and 1 (MEP, 2015).

(2) Evaluation of the importance of the function of soil conservation

The importance of the function of soil conservation was estimated by:

\[ S_{\text{sc}} = NPP_{\text{mean}} \times (1-K) \times (1-F_{\text{sl}}) \]

where \( S_{\text{sc}} \) is the serviceability index of soil conservation, and \( K \) is a soil-erodibility factor. The method emphasizes the role of green vegetation, topography, and soil structure in soil conservation and is simple and

Fig. 1. Location of the study area.
easy to use (compared to the universal soil-loss equation). It can quantitatively identify the basic spatial pattern of serviceability of soil conservation for an ecosystem and is more suitable for the rapid evaluation of large areas.

(3) Evaluation of the importance of the function of windbreaks and sand fixation

The importance of windbreaks and sand fixation was estimated by:

\[ S_{sw} = NPP_{mean} \times K \times F_q \times D \]

\[ F_q = \sum_{i=1}^{4} \frac{ETP_i \times (20 + T_i)}{ETP_{i+1}} \times (1 - r_i); \]

\[ K = 0.2 + 0.3 \exp \left\{ -0.0256 \times \frac{SAN}{100} \right\}; \]

\[ \frac{SAN}{100} \times \text{silt, clay and clayey loam soil} \]

\[ D = 1/\cos(\theta); \]

where \( S_{sw} \) is an index of serviceability of windbreaks and sand fixation; \( SAN, SIL, \) and \( CLA \) are sand, silt, and clay contents (%), respectively; \( C \) is the organic-carbon content of the soil (%); \( F_q \) is the average climatic agent of erosion over many years; \( u \) is the average monthly wind speed at a height of 2 m; \( ETP_i \) is the monthly potential evaporation (mm); \( P_i \) is the monthly precipitation (mm); \( D \) is the number of days in the month; \( T_i \) is the monthly mean temperature; \( r_i \) is the monthly average relative humidity (%); \( D \) is a surface-roughness factor; and \( \theta \) is the slope (radian). \( K, F_q, \) and \( D \) are standardized to 0–1 and then substituted into \( S_{sw} \) to calculate the index for the function of windbreaks and sand fixation.

(4) Evaluation of the importance of the function of biodiversity conservation

The importance of biodiversity conservation was estimated by:

\[ S_{bio} = NPP_{mean} \times F_{pet} \times F_{em} \times (1 - F_{lab}) \]

where \( S_{bio} \) is the serviceability index of biodiversity conservation, \( F_{em} \) is a parameter obtained from data for average annual precipitation interpolated from many years (10–30) and normalized between 0 and 1, and \( F_{lab} \) is an altitude parameter obtained from the normalization of the altitude in the evaluated region.

(5) Classified method for the importance of ecosystem services

The ecosystem services were evaluated by a Quantile analysis in ArcGIS 10.0 and were divided into four levels of importance from low to high: generally important, moderately important, important, and extremely important (MEP, 2015).

2.4.2. Identification of ecologically sensitive areas

The sensitivity of terrestrial ecosystems was mainly evaluated by assessing the sensitivities of soil loss, land desertification, rocky desertification, and river and shore zones (MEP, 2015). The ecological sensitivity of the EPRs in Zibo City were mainly evaluated by assessing the sensitivity of soil loss by water erosion (PGSD, 2016; WRDSD, 1999). The evaluation of ecological sensitivity and the grade divisions were based on regional characteristics, and the highly sensitive areas were demarcated into the EPRs and estimated as:

\[ SS_i = 4 \sqrt{R_i} \times K_i \times L_i \times C_i \]

where \( SS \) is the sensitivity index of soil loss by water erosion in space unit \( i \), and \( R_i, K_i, L_i, \) and \( C_i \) are the evaluation factors for rainwater erosion, soil erodibility, slope length and gradient slope, and surface vegetation coverage, respectively. The following are the corresponding sensitivity ratings for the evaluation factors.

(6) Evaluation of ecological sensitivity

The evaluation of ecological sensitivity and the grade divisions were based on regional characteristics, and the highly sensitive areas were demarcated into the EPRs and estimated as:

\[ SS = \text{NPP}_{mean} \times K \times F_q \times D \]

<table>
<thead>
<tr>
<th>Factor</th>
<th>R</th>
<th>K</th>
<th>LS</th>
<th>C</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insensitive</td>
<td>&lt; 25</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Mildly sensitive</td>
<td>25–100</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Moderately sensitive</td>
<td>100–400</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Highly sensitive</td>
<td>400–600</td>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Extremely sensitive</td>
<td>&gt; 600</td>
<td></td>
<td></td>
<td></td>
<td>9</td>
</tr>
</tbody>
</table>

Table 1: Soil-erosion sensitivity-evaluation index and classification.

Table 2: Grading of ecological sensitivity.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Insensitive</th>
<th>Mildly sensitive</th>
<th>Moderately sensitive</th>
<th>Highly sensitive</th>
<th>Extremely sensitive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard of grade</td>
<td>1.0–2.0</td>
<td>2.1–4.0</td>
<td>4.1–6.0</td>
<td>6.1–8.0</td>
<td>&gt; 8.0</td>
</tr>
</tbody>
</table>

Table 3: Areas of Zibo where development is forbidden.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Number</th>
<th>Area (km²)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nature reserves</td>
<td>4</td>
<td>281.86</td>
<td>4.95</td>
</tr>
<tr>
<td>Scenic locations</td>
<td>3</td>
<td>39.46</td>
<td>0.69</td>
</tr>
<tr>
<td>Forest parks</td>
<td>6</td>
<td>191.65</td>
<td>3.37</td>
</tr>
<tr>
<td>Geological parks</td>
<td>3</td>
<td>46.88</td>
<td>0.82</td>
</tr>
<tr>
<td>Wetland parks</td>
<td>6</td>
<td>28.26</td>
<td>0.50</td>
</tr>
<tr>
<td>Ecological forests</td>
<td>3</td>
<td>451.99</td>
<td>7.94</td>
</tr>
<tr>
<td>State-owned forest farms</td>
<td>4</td>
<td>63.15</td>
<td>1.11</td>
</tr>
<tr>
<td>Important areas of protection of water sources</td>
<td>17</td>
<td>46.78</td>
<td>0.82</td>
</tr>
<tr>
<td>Geological and geomorphological reserves</td>
<td>17</td>
<td>78.55</td>
<td>1.38</td>
</tr>
</tbody>
</table>

Once evaluated, ecological sensitivity was classified into five grades: insensitive, mildly sensitive, moderately sensitive, highly sensitive, and extremely sensitive (Table 2) (MEP, 2015).
2.4.3. Identification of zones where development is forbidden

Zibo has 63 areas where development is forbidden, including four nature reserves, three scenic locations, six forest parks, three geological parks, six wetland parks, four state-owned forest farms, three ecological forests, 17 important areas of protection of water sources, and 17 geological and geomorphological reserves (Table 3). Some areas where development is forbidden refer to the same area in a different category. The data were provided by the relevant management department, such as the Environmental Protection Bureau, Water Conservancy Bureau, or Municipal Bureau of Land and Resources, and corrected using remotely sensed images.

2.4.4. Data processing

The evaluations were converted to Shape format using the conversion tool in ArcGIS. The evaluations were overlaid with existing data in the exclusion area. The polymerization tool in ArcGIS 10.0 was used to polymerize the relative aggregation or adjacent element in the evaluation results after the format conversion into a new surface element with a polymerization distance of 250 m and a minimum hole of 1 km². The boundary of the block was adjusted properly using a combination of a high-resolution DOM image and land-survey data.

Independent map locations with areas < 1 km² were deleted using ArcGIS 10.0. Land for towns and large constructions and collective contiguous farmland in map locations after polymerization were deducted based on the land-use map, the plan map, and other
information. Construction land focused on towns, industrial development, mineral exploitation, and other locations such as main roads and larger villages (deducted large-scale mines on streams and abandoned mines, based on the need to maintain ecological integrity, could be retained for ecological restoration). Villages and farmland in small areas could be retained to maintain the regional integrity of the EPRs. The retained area for artificial land use in single EPR zones was ≤5%, in principle.

3. Results

3.1. Evaluation of key ecological-function areas

The extremely important, important, moderately important, and generally important areas of water conservation had areas of 1893.07, 1340.25, 1712.25, and 1019.42 km², accounting for 31.74, 22.46, 28.71, and 17.09% of the total city area, respectively (Fig. 2).

The extremely important, important, moderately important, and generally important areas of soil conservation had areas of 1230.49, 2660.10, 1729.84, and 344.58 km², accounting for 20.62, 44.60, 29.00, and 5.78% of the total city area, respectively (Fig. 3).

The extremely important, important, moderately important, and generally important areas of soil conservation had areas of 1230.49, 2660.10, 1729.84, and 344.58 km², accounting for 20.62, 44.60, 29.00, and 5.78% of the total city area, respectively (Fig. 3).
generally important areas of windbreaks and sand fixation had areas of 5.23, 672.10, 4715.84, and 571.84 km², accounting for 0.09, 11.27, 79.05, and 9.59% of the total city area, respectively (Fig. 4).

The extremely important, important, moderately important, and generally important areas of biodiversity conservation had areas of 2158.84, 1064.77, 1990.37, and 751.02 km², accounting for 36.19, 17.85, 33.37, and 12.59% of the total city area, respectively (Fig. 5).

The evaluations of the importance of the ecosystem service functions were obtained by an overlay analysis of the evaluations of the importance of water conservation, soil conservation, windbreaks and sand fixation, and biodiversity conservation (Fig. 6). The extremely important, important, moderately important, and generally important areas of ecosystem service functions had areas of 2566.46, 2209.56, 1188.54, and 0.45 km², accounting for 43.03, 37.04, 19.93, and 0.01% of the total city area, respectively (Fig. 7).

3.2. Evaluation of ecologically sensitive areas

Extremely sensitive, highly sensitive, moderately sensitive, mildly sensitive, and insensitive areas of soil loss by water erosion had areas of 1130.70, 1619.58, 920.4, 1187.04, and 1107.27 km², accounting for 18.96, 27.15, 15.43, 19.90, and 18.56% of the total city area, respectively (Fig. 8).
3.3. Confirmation of areas where development is forbidden

The total area of the areas where development is forbidden was determined after removing overlaps. The total area was 926.26 km², accounting for 15.53% of the total city area (Fig. 9).

3.4. EPR delimitation

EPRs were delimited by the overlay analysis of the areas where development is forbidden, the extremely important areas of ecosystem services, and the extremely ecologically sensitive areas, deducting small locations and large-scale artificial land. The EPRs in Zibo had a total area of 1132.26 km², accounting for 18.98% of the total city area, and were mainly distributed in the southern regions of the city (Fig. 10).

4. Discussion

Ecosystems can be damaged and ecosystem service functions can decrease by inappropriate reclamation, deforestation, overgrazing, predatory fishing, and other unreasonable human activities (Milton & Dean, 2015; Wang, Sun et al., 2015; Wang, Wang et al., 2015). China is currently confronted with serious ecological and environmental problems caused by industrialization and urbanization that are the driving factors of ecosystem changes including urbanization leading to farmland loss, the reclamation of farmlands leading to decrease of wetlands and grasslands, the exploitation of mineral resources...
leading to destruction of forest and grassland, at the same time, natural disturbances such as forest fires, earthquakes, and climate change have also diminished forest, grassland and wetland areas to some extent (Ouyang, 2016). Environmental problems such as haze in the Beijing-Tianjin-Hebei region are increasingly severe but are gradually attracting public attention (Han et al., 2016; Li & Han, 2015), and the concept of ecological protection has drawn widespread attention from the government and society. EPRs will only be established and taken seriously for the current situation required by the government. EPRs would have an important effect in improving ecosystem service functions and environmental quality by protecting important areas of ecosystem service functions and ecologically sensitive or fragile areas.

A redline of ecological protection can be one of three types of regions or redlines. The first type is an important ecological protection redline in areas with an ecological function designated, for example, for the conservation of water, maintenance of soil and water, wind protection, sand fixation, or flood regulation. This type is an ecological protection safety line to guarantee economic and social development and is a baseline of national ecological security of, for example, city water sources. The second type is a redline for ecologically vulnerable or sensitive areas. It can reduce the impact of and dangers from the external environment on cities and human settlements. The third type is a biodiversity-conservation redline, which provides the smallest safe living area for maintaining biodiversity. This redline is the baseline for survival. The safety of communities, populations, and species will be threatened if development extends beyond the redline, causing the loss
of species. Such redline areas are local protected areas for biodiversity conservation (Ou, 2016).

The conservation of biodiversity in China is a system of local networks based mainly on nature reserves and consisting of various types of protected areas, such as landscapes, popular scenery, forest parks, and wetland parks. The general trend of degradation of China's biodiversity has not yet been fundamentally curbed, although 18% of the land area of China is protected (Kou, 2015). About 90% of the country's grassland in 2015 was degraded or desertified to varying degrees, and about 40% of important wetland faced threats of degradation. Some rare and endangered species are not protected, 10.9% of the species of higher plants and 21.2% of the species of vertebrates are threatened, and genetic resources are still being lost (Shi, 2015), mainly due to the current rapid urbanization and industrialization. Many protected areas are being severely disturbed by human activities, such as deforestation, road construction, housing construction, and unreasonable tourism activities, which affect the function of protected areas and increase the threats to the habitats of the species and ecosystems. The impact of environmental pollution, excessive use of biological resources, and disorderly development of wildlife and natural ecosystems has intensified.

EPRs are spatially irreplaceable and non-repeatable and can protect areas from being eroded and provide minimum safe living areas for biodiversity conservation. The Chinese government is increasingly emphasizing the protection of the ecological environment, so EPRs have become a new strategy for national environmental protection. The
pressure of human activities on ecosystems could be greatly relieved by defining the scope of redlines, implementing the corresponding supporting policies and measures, scientifically and strictly regulating land planning and use, and improving the measures of protection and management to slow the loss of biodiversity.

EPRs include important ecological-function zones, i.e. ecologically sensitive areas and zones where development is forbidden, such as nature reserves, wetland parks, forest parks, and geological parks. EPRs are defined to identify and supplement other ecologically important and sensitive areas in addition to defining areas prohibiting exploitation by the evaluation of important ecological-function areas and ecologically sensitive areas. With the addition of existing areas prohibiting exploitation, the range of EPRs can finally be defined for protecting the integrity of important ecosystems, which would help the provision of ecosystem services. For example, the EPR area of Jiangsu accounts for 22.23% of the province's area but represents 48.69% of the value of the ecosystem services of the province. The value of ecosystem services per unit EPR area is 24 700 Yuan hm$^{-2}$, which is 2.18-fold higher than the provincial average (Yan, Zhang, Li, & Tang, 2017).

EPRs are currently in the stage of theoretical exploration, and relatively few in number. The existing identified EPRs distribution varied, for example, EPRs areas of Wuxi, Shangrao and Chishui river basin accounted for 28.69, 30.60 and 44.16% of their total area (Su, 2015; Tang & Cheng, 2015; Yang et al., 2015), respectively, which were larger than Zibo. In general, EPRs distribution varied with the distribution pattern and quality of ecosystems which were closely related to

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**Legend**

- Insensitive areas
- Mildly sensitive areas
- Moderately sensitive areas
- Highly sensitive areas
- Extremely sensitive areas

**Fig. 8. Evaluation of ecologically sensitive areas.**
ecosystem services (Grêt-Regamey et al., 2014; Ouyang, 2016; Xiao, Ouyang, Wang, & Zhang, 2016). This study provides a reference for the delimitation of EPRs. The protection of the natural resources and environment is urgent for most cities in China, but economic development is also crucial. Zibo, as a typical industrial city, relies on industrial development as its main economic lifeline. With the delimitation of EPRs, the existing main functional-area planning, overall land-use planning, urban and rural planning, and other regional planning in Zibo have been considered for setting aside space for industrial development. In addition, agricultural land is scattered in the southern concentration zone of the EPRs. Much farmland in mountainous areas is reclaimed by farmers, covering a small area, which has a negative influence on the continuous integration of EPRs. Preliminary delimitation by consultation with local authorities and farmers has appropriately reserved a lot of farmland in EPRs to maintain the integrity of the EPRs and the connectivity of the ecosystems.

Once EPRs are delimited, strict measures of management and control should be implemented to protect the long-term effectiveness of the EPRs and to achieve green development. EPRs should be managed with measures of hierarchical and zoning control. Hierarchical-control management includes national and local levels. The national level is important for the protection of national ecological security, which has an important role in key areas, such as the roles of the Yiyuan, Boshan, and Zichuan public-welfare forests in the conservation of the soil and water in the mountainous area in central Shandong. The small-scale spatial ecologically important areas, such as protected geological and

Fig. 9. Union of the areas where development is forbidden.
topographic areas, can be classified as local protection. Zoning control could divide EPRs into different zones of ecosystem service functions based on the dominant ecological function, including zones of water conservation, both soil and water conservation, windbreaks and sand fixation, and biodiversity conservation. Management strategies would also be developed based on the possible human disturbance of the ecosystem service function. The relevant planning should meet the requirements of EPR spatial control, and the adjustment should be rapid. As the baselines for national spatial development, EPRs should be an important basis for spatial planning. A monitoring network and platform should be established to monitor real-time human activity in EPRs. Moreover, research for ecological-protection compensation should be strengthened for protecting EPRs (Xinhua, 2017).

China proposed EPR delimitation in 2011, so some research and practical work have made some progress (Lu, Liu, Xiang, Song, & McIlgormc, 2015; Wang, Sun et al., 2015; Wang, Wang et al., 2015). Many related theories, however, remain unclear, e.g. the complete implementation of EPRs, techniques and methods for monitoring and supervision, and mechanisms of ecological compensation, which should be the foci of further research.

5. Conclusion

The value of protecting ecological and natural resources has been recognized in China. EPRs are being introduced to identify ecological baselines for the protection of the environment and its resources. EPRs
in Zibo consist of important ecologically functional areas (key areas of ecosystem service functions), ecologically sensitive areas (soil loss by water erosion), and areas where development is forbidden (legal areas containing natural and human resources). The importance of the ecosystem service functions of water conservation, soil conservation, windbreaks and sand fixation, and biodiversity conservation were evaluated based on NPP. Extremely important areas of ecosystem service functions had an area of 2566.46 km², accounting for 43.03% of the total city area. Extremely sensitive areas of soil loss by water erosion had an area of 1130.70 km², accounting for 18.96% of the total city area. The total area of 62 areas where development is forbidden was 926.26 km², accounting for 15.53% of the total city area. The EPRs in Zibo had a total area of 1132.26 km², accounting for 18.98% of the total city area, and were mainly distributed in the southern regions of the city.

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