Evidence of green space sparing to ecosystem function improvement in urban regions: A case study of China's Ecological Red Line policy

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Title Page

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Abstract

The debate on land-sparing versus land-sharing has continued for decades regarding which of the two approaches can optimize the yield-conservation tradeoff. Current opinions are mostly criticisms for the overly-narrow focus on specific biodiversity conservation and simplistic solution to the agri-environmental scheme. This study based on limitations in previous studies aims to advance the land-sparing versus land-sharing framework from two perspectives. First, the extended framework highlights the tradeoffs between built-up land and green space in urban regions. Second, the multi-functionality of natural land is characterized by various ecosystem services rather than merely biodiversity. To demonstrate the applicability of the framework, a practical case of green space sparing—the Ecological Red Line (ERL) policy currently implemented across China—was elaborated. Particularly, soil retention was selected as a proxy to compare the difference between green space and unprotected areas. It showed that (1) the soil retention difference between areas inside and outside the ERL continued steady before the implementing of the ERL and thereafter presented upward trend. (2) the aggregate pattern and scale of soil retention changed obvious after the implementing of the ERL. (3) environment factors underlying the spatial variation of soil retention varied in inner and outer areas of the ERL, and the ERL might ameliorate soil retention of different land use types by spill-over effect. These findings demonstrated the effectiveness of the ERL, and further supported that the green space sparing is a promising strategy for urban land management. The ERL case study provides empirical evidence to support applications of
the extended land-sparing versus land-sharing framework in urban regions.

**Keywords:** Land-sparing; Land-sharing; Urban; Greenspace; Ecological Red Line; Land use.
1 Introduction

Land system is frustrated with human-induced transformations or otherwise under anthropogenic stresses, while simultaneously being with unexpected capacity to sustain human well-being (Soga et al., 2014). In the context of global change and ecological degradation, land system science integrates different dimensions of global change and operates at the interface of the social and natural sciences (Verburg et al., 2013). It is acknowledged that land system science is prominent in offering a wide range of adaption and mitigation solutions to achieve sustainable goals.

The land-sparing versus land-sharing framework (Green et al., 2005), one of various land-based solutions, was originally proposed to disentangle the trade-offs between two indispensable human demands: food production and biodiversity conservation. Specifically, it advocates two extreme land use patterns, with agricultural land and natural land separated versus integrated. The land-sparing approach highlights that farming poses great threat to wild population (Rudel et al., 2009), arguing for agriculture intensification to conserve separate and continuous natural land. By contrast, the land-sharing approach argues for integrating natural land and farmland for the purpose of high landscape heterogeneity (Tscharntke et al., 2012; Paul et al., 2019).

It is controversial regarding which of the two approaches better combines efficient agricultural land use with biodiversity conservation, despite increasing empirical studies (Marr et al., 2016). A total of 234 papers in the Web of Science database were selected and conducted to seek generalization findings surrounding the debate. There are 85 papers
with definite preference for land-sparing. Another 46 papers show preference for land-sharing. The remaining 103 papers suggested that land-sparing and land-sharing have both superiorities and inferiorities. Specifically, land intensification and agricultural expansion were found to be incompatible with wildlife population and natural generation (Sato et al., 2016; Lathuilliere et al., 2017). And natural land was protected well against fragmentation in most land-sparing cases (Lamb et al., 2016). The land-sparing was endorsed as a more promising strategy for minimizing negative impacts of human-dominated land transformation at both current and anticipated future levels of production (Phalan et al., 2011). Indeed, applications of the land-sparing strategy were not successful in some regions. It has been argued for exacerbating spillover effects into adjacent natural land with net conservation gains decrease with increasing intensification (Didham et al., 2015). In addition, biodiversity continues a decline trend especially in large-scale protected areas for the effect of the power of governance regimes (Rosemary et al., 2015). Under the circumstances, land-sharing was appreciated for ‘heterogeneity, resilience, and ecological interactions between natural land and farmland’ (Fischer et al., 2008). The land-sharing approach hinges on coexistence of conservation and production (Arnauld et al., 2016), which is in turn fastidious about the planning and management. When the lens focused on urban system, there is little consensus on how to effectively utilize land as well. The huge coverage of green space has gained considerable attention for delivering benefits and sustaining ecological integrity (Forleo and Palmieri, 2018; Hummel et al., 2019). It is suggested that critical green space should be spared as the priority areas to be protected (Chape et al., 2005; Saura and Pascual, 2007). While the
scattered green space is argued to be planned across residential areas for convenient access. To date, the debate on land-sparing or land-sharing remains inconclusive. And evidence in favor of either land-sparing or land-sharing is so far limited in urban regions. More importantly, criticisms have been increasing on the dichotomous framework of land-sparing versus land-sharing. On the one hand, existing solutions to the agri-environmental scheme are criticized as overly simplistic characterizations of the framework. Despite that agriculture is a primary human activity across the world, the dominant anthropogenic disturbance occurs in urban regions, with crying needs of reconciling the land use tradeoffs between built-up areas and natural land (Grimm et al., 2008). In this vein, strong couplings between agricultural and urban systems have been highlighted recently (Lin et al., 2013; Soga et al., 2015). And a few case studies have attempted to adapt the land-sparing versus land-sharing framework for applications in urban systems as well (Stott et al., 2015). For example, Lin et al. (2013) defined land-sparing in urban system as high-density, built-up land with a separate, large, continuous natural space set aside. Soga et al. (2014) quantified the conservation benefits of land-sparing and land-sharing developments in cities, and found that land-sparing and land-sharing showed different conservation benefits at different urbanization levels. Nonetheless, researches are still in the early development stages, and more case studies are needed to consolidate the appropriateness of land-sparing and land-sharing framework in the urban context. On the other hand, the dichotomy is criticized for its overly-narrow focus on merely biodiversity conservation and food production. While a growing consensus is that reconciling only the relationship between agricultural yield and
biodiversity may lead to losses of other crucial ecosystem services (Caryl et al., 2016). In fact, natural land is multi-functional with capacity to deliver functions such as carbon sequestration, air and water purification, recreation, local climate cooling, and so on (Burkman and Gardiner, 2014; Pataki et al., 2011; Hu et al., 2019). In this regard, studies on this framework should look beyond food production and biodiversity conservation (Armsworth et al., 2007).

The present study aims to advance the land-sparing versus land-sharing framework by addressing the above-mentioned limitations. Figure 1 shows the extended framework that encompasses the traditional agricultural system as well as new urban system. The extended framework highlights the tradeoffs between built-up land and green space, thus possible to address urban land management challenges. Moreover, the multi-functionality of natural land is characterized by various ecosystem services rather than merely biodiversity. The theory, methodology and research paradigm studied in the context of the agri-environmental system for navigating tradeoffs between farmland and natural land remain as the core research objects. This is important to note that farmland is viewed as green space in urban system given that it delivers more ecosystem services in comparison with built-up land. In doing so, the conflict between built-up areas sprawl with green space conservation can be explicitly addressed. To explore the applicability of the land-sparing versus land-sharing framework in urban regions and the feasibility of other ecosystem services, a practical case of green space sparing case—the Ecological Red Line (ERL) policy currently implemented across China—was elaborated. In particular, soil retention, as an inextricable component of natural land function, was selected as a proxy
of ecosystem services to examine the effectiveness of the green space utilization strategy. The difference of soil retention between areas inside and outside the ERL was compared by calculating the inner-to-outer ratio, cluster and outlier analysis and geographical factors. To recap, the findings support green space sparing as a promising strategy for urban land management. This study directs the ongoing land-sparing and land-sharing debate toward a more comprehensive direction and could provide practical guidance for land use policy makers.

Fig. 1. Theoretical framework for extending the Land-sparing versus Land-sharing strategies.

**2 Case study**

**2.1 Ecological Red Line policy**

The Ecological Red Line (ERL) policy was first issued in Shenzhen in 2005 given that green space situation is pretty grim. The ERL covers a majority area of green space with 974 km$^2$, accounting for almost 49.9% of the total land of Shenzhen. In the past few years, the ERL has played a pivotal role in curbing the disorderly expansion of built-up areas,
while conserving ecological integrity. China central authorities appreciated this policy instrument and thus determined to establish an ecological protection “red line” system throughout the country. It has been declared that the demarcation of the border and calibration of the “red line” regions with important ecological functions would be completed by the end of 2020.

2.2 Study area

Shenzhen, is located in the east coast of the Pearl River Delta megalopolis, China, adjacent to the south of Hong Kong (113°46′–114°37′ E; 22°27′–22°52′ N). This city covers a total area of 1996.85 km² with eight districts (Fig.2). The terrain of Shenzhen is high in the southeast and low in the northwest, being exposed to a subtropical sea monsoon climate. In addition, Shenzhen was singled out to be the first Special Economic Zone in 1980 in China. It develops from a former border town to an important international city, creating a rare pace of industrialization and urbanization. Its GDP rose about 7.5 percent year-on-year to surpass 354 billion U.S. dollars in 2018. However, in the process of urbanization, Shenzhen is faced with the dilemma of reconciling built land sprawl with ecological conservation.
2.3 Data source

The Land Use Investigation is carried out every year in Shenzhen for the renewal and maintenance of land utilization. The land-use data for a fourteen-year period was obtained from related department of Shenzhen government. The precipitation data from 2000 to 2013 were collected from China Meteorological Data Service Center (http://data.cma.cn/) and Shenzhen Meteorological Data System (https://data.szmb.gov.cn/). There are 31 ground observation stations providing with detailed annual and monthly rainfall data. Soil attribute data was obtained from the Harmonized World Soil Database. The Normalized Difference Vegetation Index (NDVI) was obtained from SPOT-Vegetation carried out by SPOT-4, with a spatial resolution of 1 km. The date is January 1st, 2013. The DEM data (30-m) was obtained from the Geospatial Data Cloud (http://www.gscloud.cn/).

2.4 Methods

It is necessary to quantify the soil retention at first using the InVEST model which is widely appreciated for its ecosystem service evaluation and mapping. The criteria for
determining crucial parameters of soil retention is illustrated in the 2.4.1 section, and
details of methods can be found in the InVEST User’s Guide (Richard et al., 2014).
Buffer analysis is based on spatial diagnosis and viewed as part of the neighborhood
analysis (Li et al., 2016). The 500-m and 1-km radius buffers were set for the reason that
the mapped soil retention showed spatial agglomeration in a specific distance along the
ERL(Fig.2). The difference of soil retention between areas inside and outside the ERL is
depicted by total amount analysis, cluster and outlier analysis and geographical detectors.

2.4.1 Assessing the soil retention

The critical parameters of soil retention refer to rainfall erosivity and soil erodibility
index. The rainfall erosivity index was calculated by the Wischmeier and Smith’s monthly
scale formula (Wischmeier et al., 1978).

\[ R = \sum_{i=1}^{12} (1.735 \times 10^{(1.5Ig\frac{P_i}{P}) - 0.8188}) \] (1)

Where \( R \) is the rainfall erosivity, \( P \) is the average annual precipitation (mm), and \( P_i \) is the
average monthly precipitation (mm). The \( R \) further performs unit conversion from
MJ.mm/ (hm².ha) to MJ.mm/ (ha.h.yr) through multiplicative conversion factors with a
value of 17.02.

The soil erodibility index is a measure of the susceptibility of soil particles to detach and
be transported by rainfall and runoff. It was calculated by an equation provided by the
United States Department of Agriculture (Sharpley and Williams, 1990).

\[ K = 0.1317 \times \left[ 0.2 + 0.3 \times \exp \left( -0.0256 \times \text{SAN} \times \left( 1 - \frac{\text{SIL}}{100} \right) \right) \right] \times \left( \frac{\text{SIL}}{\text{CLA} + \text{SIL}} \right)^{0.3} \times \left[ 1 - \frac{0.25 + \text{C}}{\text{C} + \exp(3.72 - 2.95\times \text{C})} \right] \]

\[ \left[ 1 - \frac{0.7 \times \text{SN}_1}{\text{SN}_1 + \exp(-5.51 + 22.9 \times \text{SN}_1)} \right] \] (2)
\[ S_{Ni} = 1 - \frac{SAN}{100} \]  

(3)

Where \( K \) is the soil erodibility (t.ha.hr. (ha.MJ.mm)\(^{-1} \)), and \( SAN, SIL, CLA, C \) are the content of sand, silt, clay, and organic carbon, respectively.

The support practice factor (\( P \)) and the cover-management factor (\( C \)) is necessary for soil retention assessment. They were estimated based on previous studies (Long et al., 2012) and the RUSLE handbook (Renard et al., 1997).

2.4.2 Diagnosing the spatial aggregations of soil retention

There are different adjacent or surrounding situations for different elements in the geographical space. The cluster and outlier analysis were used to examine the spatial situation of soil retention. In ArcGIS software, this tool is set based on Anselin Local Moran’s I (Anselin, 1995), which is widely used to identify statistically significant hot and cold spots. Given that the input features of the cluster and outlier analysis tool is supposed to be vector format, the grid of soil retention output by the InVEST model was therefore converted to vector points at first. The number of vector points was determined by the spatial resolution (30-m) of output soil retention as well as the scope of study area.

In particular, the soil retention service was not delivered in specific land use, such as built-up land. In other words, there grids were with null value and should be removed. Consequently, there were 9684 and 9751 vector points in the 1-km radius buffer inside and outside the ERL respectively. The next step was to identify the spatial associations of soil retention inside and outside the ERL by applying the rook contiguity. Four types of spatial associations were defined, including High-High (HH), High-Low (HL), Low-High
(LH) and Low-Low (LL) associations. The HH denotes that regions with high soil retention are surrounded by neighbors with high values, while LL denotes that regions with low soil retention area surrounded by neighbors with low values. The HL denotes that regions with high soil retention are surrounded by neighbors with low values, while the LH denotes that regions with low soil retention are surrounded by neighbors with high soil retention. Finally, the scale of HH association was assessed by counting number of vector points.

2.4.3 Detecting potential environmental factors

If there is a significant correlation between environmental factors and geographical variations, the occurrence and development of this factor will be decisive (Wang et al., 2010). Geographical elements are always distributed in specific spatial locations. The geographical detectors was adopted to identify underlying associations between soil retention and various environmental factors based on the consistency of their spatial distribution. Excessive assumptions in the geographical detectors would be overcome compared with traditional statistical analysis. The relationship of soil retention and environmental factors was measured by the following equations (Wang et al., 2010):

\[ q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma^2_h}{N \sigma^2} \tag{4} \]

Where \( \sigma^2 \) is the variance of soil retention, \( \sigma^2_h \) is the division variance in strata \( h \), \( N \) is the size of the study area, \( N_h \) is the size of strata \( h \); The range of \( h \) is from 1 to \( L \). The \( q \) ranges from 0 to 1. The soil retention will not be spatially stratified as heterogeneous when the \( q \) value is zero, while it will be completely determined by environmental factors when the \( q \)
value is 1.

In this part, the dominant environmental factors affecting the spatial variability of soil retention were selected and identified. There are previous studies available on the potential environmental factors (Brambilla et al., 2017; Diwediga et al., 2018). As a result, the annual rainfall, altitude, slope, aspect, Normalized Difference Vegetation (NDVI) and land use type were selected to explore the difference of soil retention between areas inside and outside the ERL. In particular, there are roughly eleven types of land use inside the ERL, including arable land, grass, water body, forest, woodland, bare land, greenbelt, orchard, traffic land, and built-up land.

3 Results

3.1 The relative difference of soil retention between inner and outer areas

The inner-to-outer ratio of soil retention was calculated for analyzing the relative difference between areas inside and outside the ERL. The graph (Fig. 3) showed time trend of total soil retention in 500-m and 1-km radius buffers from 2000 to 2013. Over a span of 14 years, the ratio continued to be greater than 4, pronouncing that the soil retention inside was substantially greater than outside. The trend of ratio in the 500-m radius buffer varied with time, in accordance with in the 1-km radius buffer. Additionally, the soil retention in 1-km radius buffer was less than twice in 500-m radius buffer. It hinted the edge effect that high density of soil retention aggregated in the border area of the ERL.

The ratio curve remained steady before 2005, with the value being approximately 4.61
and 6.69 in the 500-m and 1-km radius buffers, and fluctuated thereafter. In particular, the ratio underwent a dramatic decrease in 2008 in both 500-m and 1-km radius buffers, with the value being approximately 4.53 and 6.55 respectively. Furthermore, the ratio continued a downward trend from 2009 to 2011, and plateaued in 2009 with the value being 5.1 and 7.89 respectively. The ratio curve was further divided into three stages at five-year intervals accordingly. The average line was added and showed upward trends for both 500-m and 1-km radius buffers. It was around 7.19 and 4.83 from 2000 to 2004, and increased to 4.83 and 7.19 from 2005 to 2013, compared to 6.75 and 4.62 before the implementation of the ERL.

![Graph showing inner-to-outer soil retention ratio and average line from 2000 to 2013. The graph illustrates the ratio at five-year intervals and displays the average line. The vertical axis on the left indicates the inner-to-outer soil retention ratio for 500-m and 1-km radius buffers. The horizontal axis represents the years from 2000 to 2013. The average line shows an upward trend for both radius buffers, with values around 7.19 and 4.83 from 2000 to 2004, increasing to 4.83 and 7.19 from 2005 to 2013, compared to 6.75 and 4.62 before the implementation of the ERL.]

3.2 The spatial aggregate pattern and scale of soil retention

Figure 4 showed statistically significant spots of soil retention from 2000 to 2013. Four
types of aggregations—the HH, LL, HL and LH associations—occurred in the inner and outer areas of the ERL (Fig. 4). The HH association was the leading aggregation for both the inner and outer areas of the ERL, accounting for approximately 80 per cent of statistically significant hot and cold spots. The HH aggregations were widespread along the ERL and mainly distributed in the southern coast of Dapeng and the east of Baoan district which covered two green corridors, Shiyan-Bantian and Pingshan-Kengzi. It indicated that these regions were hotspots with high and relatively homogeneous soil retention. The LL association mainly occurred in the inner area of the ERL after 2005, and its aggregations were distributed in the border of Nanshan and Baoan districts. There were LL aggregations scattered outside the ERL in 2008 and distributed in the northwest of Longgang and Longhua districts. These regions with LL associations provided low levels of soil retention.
Fig. 4. Aggregation patterns of soil retention from 2000 to 2013. The shaded portion is green space within the ERL. The colored points are those that contribute significantly to a positive global spatial autocorrelation outcome. HH denotes regions with high soil retention and surrounded by neighbors with high soil retention. LL denotes regions with low soil retention and surrounded by neighbors with low soil retention. LH denotes regions with low soil retention but surrounded by neighbors with high soil retention. HL denotes regions with high soil retention but surrounded by neighbors with low soil retention.

Specifically, the HH association was focused to analyze the effect of the ERL to soil retention. The scale of HH association inside the ERL was significantly higher than the outside. It fluctuated between 5672 and 6682 from 2000 to 2006, continued to climb to a peak in 2012 in the inner areas of the ERL (Fig.5). In contrast, the aggregate scale in the outer areas remained roughly steady throughout the whole period and stood at 393 in 2012. The minimum value was saw in 2007 outside the ERL, with the value being 249. The average line was added to depict time trend of the aggregate scale. Its value was around 6048 inside the ERL and 404 outside the ERL from 2000 to 2004. After the implementation of the ERL in 2005, the average line in the inner areas climbed from 6221 to 6493, while the value in the outer area climbed from 313 to 719.
Fig. 5. The scale of the HH association at the 1-km radius buffer from 2000 to 2013. The vertical axis in the left denotes the number of points with HH associations inside the ERL. The vertical axis in the right denotes the number of points with HH associations outside the ERL. The average value was calculated at five-year intervals and displayed as the average line.

### 3.3 The explanatory power of potential environmental factors

Seven environmental factors were selected to explain the spatial variability of soil retention (Tab.1). In the inner 1-km radius buffer, the slope saw the highest q value. It indicated that slope was dominant in determining the spatial variability of inside soil retention, with an explanatory power of approximately 19.12%. The aspect saw the lowest q value (0.38%), showing the weakest explanatory power for the spatial variability of inside soil retention. The q value of altitude was around 7.88%. It was followed by the NDVI, geographical location and land use pattern, with the q value at 5.9%, 5.50%, and 4.88%, respectively. The annual rainfall showed a weak influence on the spatial variability of soil retention inside, with a q value at 4.64%.
In the outer areas of the ERL, the slope saw the highest q value (27.39%) and the aspect saw the lowest q value (0.2%), which is consistent with results in the inner areas. It was noteworthy that the land use showed strong explanatory power for the outer soil retention, with a q value at 6.15%. Meanwhile, the q value of altitude in the outer areas was only about 2.96%, compared to 7.88% in the inner areas. It was followed by the NDVI, geographical location and annual rainfall, with the q value at 2.7%, 2.6%, and 1.73%, respectively.

Additionally, all environmental factors except for slope and land use saw higher q value in the inner areas of the ERL when compared with results in the outer areas. The q value of the slope varied from 19.12% inside to 27.39% outside. The q value of the land use varied from 4.88% inside to 6.15% outside.

### Table 1. Potential environmental factors for explaining the spatial variability of soil retention

<table>
<thead>
<tr>
<th>Inner areas</th>
<th>Outer areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>q value</td>
<td>p</td>
</tr>
<tr>
<td>Altitude</td>
<td>0.0788 0</td>
</tr>
<tr>
<td>Annual rainfall</td>
<td>0.0464 0</td>
</tr>
<tr>
<td>Slope</td>
<td>0.1912 0</td>
</tr>
<tr>
<td>Aspect</td>
<td>0.0038 0</td>
</tr>
<tr>
<td>Land use</td>
<td>0.0488 0</td>
</tr>
<tr>
<td>Geographical location</td>
<td>0.0550 0</td>
</tr>
<tr>
<td>NDVI</td>
<td>0.0590 0</td>
</tr>
</tbody>
</table>

The amount of soil retention for each land use type was further calculated (Tab.2). In the inner areas of the ERL, forest showed the highest soil retention, with a value approximately 807732.89. It was followed by orchard, other woodland, and shrub, with the value around 213407.17, 56233.34 and 52345.94, respectively. Greenbelt showed the lowest level of soil retention, with a value approximately 2516.36. In the outer areas of
the ERL, forest, orchard and other woodland showed high levels of soil retention, with the value approximately 100786.07, 34643.96 and 16702.85 respectively, which were consistent with results inside the ERL. Greenbelt saw the lowest soil retention as well. In particular, shrub showed a low delivery of soil retention outside the ERL, with a value at 4705.11.

All land use types except for grass and bare land saw higher levels of soil retention inside the ERL when compared with results outside. And the difference in forest, orchard and shrub were more significant. Grass see the minimum soil retention change between the inner and outer areas, with the difference being approximately 124.58. It was followed by greenbelt with the difference being approximately 1376.3. It was particularly noteworthy that bare land increased soil retention from 11016.88 inside the ERL to 16555.68 outside.

Table 2. Total amount of soil retention for different land use types in 2013

<table>
<thead>
<tr>
<th>Land use type</th>
<th>Inner areas (tons)</th>
<th>Outer areas (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arable land</td>
<td>6374.8588</td>
<td>3276.9595</td>
</tr>
<tr>
<td>Grass</td>
<td>5290.9499</td>
<td>6045.5292</td>
</tr>
<tr>
<td>Bare land</td>
<td>11016.8783</td>
<td>16555.6841</td>
</tr>
<tr>
<td>Greenbelt</td>
<td>2516.3585</td>
<td>1140.0569</td>
</tr>
<tr>
<td>Orchard</td>
<td>213407.1652</td>
<td>34643.9639</td>
</tr>
<tr>
<td>Forest</td>
<td>807732.8915</td>
<td>100786.0709</td>
</tr>
<tr>
<td>Shrub</td>
<td>52345.9433</td>
<td>4705.1083</td>
</tr>
<tr>
<td>Other woodland</td>
<td>56233.3407</td>
<td>16702.8452</td>
</tr>
</tbody>
</table>

4 Discussion and Conclusions

4.1 Discussion

4.1.1 Interferences on inter-annual variations of soil retention.

In previous studies, insufficient considerations were given to eliminate interferences from environmental factors when the effectiveness of a policy instrument was evaluated. This
study emphasized that the interference from external environment should be removed.

In the infancy of this study, an absolute difference of soil retention between the inner and the outer areas was calculated (Fig.6). It showed a fluctuation with unobvious trend during the period from 2000 to 2009 and an upward trend thereafter. We inferred that the input environmental factors of soil retention might have a great influence on the inter-annual variations, thereby eventually led to the fuzzy difference between the inner and the outer areas. Precipitations are one of important factors which is significantly correlated with the soil retention output (Arnoldus, 1977; Roose, 1977; Lu et al., 2017). It has been found that 90% of the spatial variation in the R-factor of soil retention was explained by variations in average annual rainfall (Lo et al., 1985), and the intensity and duration of rainfall would positively influence the soil retention output. In addition, the land use pattern and topographic features would increase variations or add noise in inter-annual soil retention as well (Beehler et al., 2017; Brambilla et al., 2017).

In the above-mentioned section 3.1, the inner-to-outer ratio was calculated by excluding the greatest common factors rather than the absolute difference by simple subtraction. The ratio curve presented a credible change trend, and seems to be effective for eliminating interferences from external environment to some extent (Fig.3). This method would mitigate inferences owing to regulation and management as well with the help of buffers setting. However, there were some incommensurable factors in the inner and outer areas of the ERL, which need further analysis. In general, it is a great challenge to distinguish how much the ERL is actually responsible for the promotion of soil retention.
Fig. 6. The absolute difference of soil retention between the inner and the outer areas. “1-km” denotes the 1-km radius buffer. “500-m” denotes the 500-m radius buffer. The value is calculated by the soil retention inside minus the outside.

4.1.2 Occurrence of HH and LL associations after the implementation of the ERL

The scale of HH association in the inner areas presented an upward trend after the implementation of the ERL (Fig.5). While the aggregate scale in the outer areas leveled off throughout the whole period. It thus demonstrated the effectiveness of the ERL. However, there were some regions inside the ERL with low levels of soil retention (Fig.4). And some regions found new HH and LL aggregations after the implementation of the ERL.

It is difficult to understand mechanisms behind these phenomenon. At first, the lack of corresponding supervision after the issue of the ERL was more likely to be responsible for the abnormal. Policy-makers and urban planners are faced with contradiction between utility maximization and welfare preferences, and have to adjust environmental targets and outputs frequently. Moreover, the power of the governance regimes could be weakened by green space expansion thereby speeding the ecological degradation (Hill et
Green space in this study was enclosed by the ERL and dispersed throughout eight districts under different management and investment conditions. It showed that the district with large coverage of green space was more likely to undergo occurrence of LL associations. In general, the lack of supervision targets, the regional difference in management and investment as well as the lack of unified ecological planning might be reasons underlying the occurrence of HH and LL associations after the complementation of the ERL.

### 4.1.3 The explanatory power of potential environmental factors in 2008

Environmental factors in 2013 were identified to show differences between the inner and the outer areas of the ERL. The availability of data and reliability of results should be discussed. Here the data in 2008 was supplemented to defend finding for considering that the inner-to-outer ratio showed a dramatic decrease in 2008.

Most results in 2008 were consistent with results in 2013. Topographic features, including the slope and the altitude, were dominant in explaining the spatial variability of soil retention in 2008 (Tab.3), which was equally characterized in 2013. NDVI could largely explain the spatial variability of soil retention in 2008, which was well consistent with results in 2013. The annual rainfall and aspect showed weak explanatory capacity in 2008 as well as in 2013. In addition, all environmental factors except for slope and land use saw higher q value in the inner area of the ERL when compared with results in the outer areas.

There existed disagreements in the variation of explanatory power with regard to NDVI...
and land use outside the BEL. The q value of the NDVI was about 4.41% in 2008, compared to 2.7% in 2013. The q value of the land use was around 4.02% in 2008, compared to 6.15% in 2013. The disagreement could be attributed to anthropogenic interferences in the outer areas of the ERL. In other words, the changes of NDVI and land use were human-induced transformations. Overall above results supported conclusions in 3.3 section despite of some disagreements.

<table>
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<th>Inner areas</th>
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</table>

4.1.4 Applications and possible future of the land-sparing versus land-sharing framework

In fact, there are a series of practices in China taking cue from the sparing versus sharing framework. For example, the Regulation on the Protection of Basic Farmland was implemented by sparing finite farmland to promote agricultural production and to sustainable social and economic development; Moreover, the delimitation of Production-Living-Ecological space and the functional zoning policy synthesize split and shared patterns as well (Liao et al., 2019). It is notable that there are two dominant development forms in urban system, sprawling and compact urban (Sperandelli et al., 2013). Specifically, the sprawling urban is characterized as unrestricted development with
consuming large amounts of undeveloped land near a city (Jabareen, 2006), while the compact urban controls the spread of suburbs into open lands and is characterized as high-density development (De Roo et al., 2000). The sprawling and compact urban substantially resonate with the concept of land-sparing versus land-sharing.

Overall, the idea of sparing versus sharing is not novel in practice in China. It seems that land-sparing pattern is more popular especially when certain conservation goal is set. Current situation is that theoretical framework and systematic methodology are insufficient to underpin multiple pathways of land use. The land-sparing versus land-sharing framework could be formulated to understand mechanisms behind different land use approaches and guide practices in both agricultural and urban systems. Simultaneously, the extensive land use practices accumulated knowledge for the debate on land-sparing versus land-sharing.

The ERL case is selected in this paper for its superiority of temporal and spatial conditions. On the one hand, the ERL in Shenzhen city was first designated in 2005 and continued up to now, which offered more time to examine the plausible ecosystem service change and in turn demonstrate the effectiveness of the policy instrument. On the other hand, the ERL enclosed the majority of green space, accounting for almost 49.9% of the total land of the city, to safeguard ecological safety. It is a typical land-sparing practice on city scale.

Some limitations existed in the applications of the extended land-sparing versus land-sharing framework. Firstly, the applicability of other ecosystem services needs to be comprehensively discussed. It has been mainstreamed to distinguish provisioning,
regulating, cultural and supporting services. The soil retention, classified as a regulation service, has been used to analyze the effective of urban space sparing. Efforts are suggested to integrate other ecosystem services for coherent approaches to practical application of the framework. Secondly, there exist uncertainties for ecosystem service assessment. The connections between ecosystem processes and functions are complex and the variations pathways are still not well understood (De Groot et al., 2010). Although a precautionary approach has taken to assed the soil retention here, the deviations are inevitable.

Future development of the land-sparing versus land-sharing framework should shift out from agri-environment and urban system and move toward a more transdisciplinary approach. The idea of sprawling and compact urban could be integrated into “sparing versus sharing” paradigm. The research paradigm of landscape ecology have a lot to offer in the way of guidance as well. The trend of land-sparing versus land-sharing framework is likely to explore appropriate spatial heterogeneity for human demand at the least cost to wild nature.

4.2 Conclusions

The novel land-sparing versus land-sharing framework described in this paper integrated environmental pressure in the agricultural and urban system. Moreover, the multi-functionality of natural land in the framework is characterized by various ecosystem services rather than merely biodiversity. It provides a strategic approach for planners and stakeholders to make multi-functional use of land resources, which goes
beyond traditional spatial pattern and process paradigm.

There are three major findings in the case study. First, the ERL can increase the difference of soil retention between inside and outside areas. The inner-to-outer ratio of soil retention continued steady before implementing the ERL and thereafter presented obvious upward trend, indicating that the difference indeed changed. Second, the ERL can enhance the spatial agglomeration of soil retention output. Significant differences in the aggregate pattern and scale of soil retention between inside and outside areas were found. The aggregate scale of HH association fluctuated between 5672 and 6682 from 2000 to 2006, continued to climb to a peak in 2012. While the aggregate scale in the outer areas remained roughly steady throughout the whole period and stood at 393 in 2012. Third, environmental factors underlying the spatial variability of soil retention varied in inner and outer areas of the ERL. The altitude showed strong explanatory power for the inner soil retention, with a q value at 7.88%. While outside the ERL, the land use was more likely to responsible for the variability of soil retention, with a q value at 6.15%. Additionally, the ERL might ameliorate soil retention of different land use types by spill-over effect. All land use types except for grass and bare land saw higher levels of soil retention inside the ERL when compared with results outside.

The applicability of the framework especially in reconciling tradeoffs between built-up land and greenspace was demonstrated. It suggested that the ERL is an effective approach to improve soil retention. In other words, green space sparing is a promising strategy for minimizing negative impacts of urbanization.

In general, the ERL case study provides empirical evidence to support further applications
of the extended land-sparing versus land-sharing framework in urban regions. Further studies can advance by further examining the uncertainties in quantifying soil retention, and by researching the response of other ecosystem services.

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Data Accessibility

https://figshare.com/s/7881ce320fc3eb52e1cd

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: