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# Spatial impact of Cropland Supplement Policy on regional ecosystem services under urban expansion circumstance: a case study of Hubei Province, China

Xinli Ke[a], Qiushi Zhou[a], Chengchao Zuo[a*], Lanping Tang[a], Andy Turner[b]

[a]*College of Public Administration, Huazhong Agricultural University, Wuhan, 430070, PR China;* [b] *School of Geography, University of Leeds, Leeds, LS2 9JT, UK*

E-mail address:

kexl@igsnrr.ac.cn (X.Ke); pawn_zzz@webmail.hzau.edu.cn(Q.Zhou); c.zuo@mail.hzau.edu.cn (C. Zuo);tlp0809@163.com (L. Tang); a.g.d.tuner@leeds.ac.uk(A. Turner)

* Corresponding author:

Chengchao Zuo

Huazhong Agricultural University, Wuhan, Hubei Province,430070

+86 (0) 15527861671

c.zuo@mail.hzau.edu.cn

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# Spatial impact of Cropland Supplement Policy on regional ecosystem services under urban expansion circumstance: a case study of Hubei Province, China

**Abstract:** The Cropland Supplement Policy (CSP) helps maintain the total area of cropland in China as urban areas expand, but can result in environmental degradation as areas of more natural habitat are turned into cropland. Current and future impacts of the CSP are explored under different land use change scenarios by comparing the differences in ecosystem services value (ESV) at prefecture level. Scenario based simulation results suggest that in Hubei province, the CSP cost 19.53 billion CNY in the period 2000 to 2015 and would cost an additional 12.54 billion CNY in the period 2015 to 2030 in terms of ESV loss. A policy analysis framework for land use planning is proposed which enables ecological impacts of the CSP to be considered.

Keywords: Cropland protection; Cropland supplement policy; Ecosystem protection; Ecosystem Services Value; Land use change model

## 1. Introduction

More than 50% of people now live in urban areas, this proportion is expected to reach 68.4% by 2050 (United Nations, 2018). Whilst more people can be accommodated into existing urban areas, typically urbanization involves expanding urban areas (Seto et al., 2012). McDonald et al. (2018) forecast a worldwide increase of 120 million hectares of urban land from 2000 to 2030, and in many cases the expansion will be at the expense of some highly productive farmland (Angel et al., 2011; Xin & Li, 2018). Martellozzo et al. (2015) reported that in Canada around 60% of the urban area built in the Calgary-Edmonton corridor between 1988 and 2010 occupied land that was previously cropland, and unsurprisingly agricultural productivity in the area fell as a result. van Vliet et al. (2017) estimates that by 2050, due to urban expansion, agricultural production in the close vicinity of large cities will be 65 million tons less. Global population is expected to increase significantly in the coming years, and people are preferring to consume products requiring more land to produce (Seto & Ramankutty, 2016). Thus at a global scale, the demand for agricultural land is increasing. What is typically being lost are many more natural habitats and areas of wetland and forest, and this is a major concern documented by numerous case studies (Gibbs et al., 2010). Typically, wetlands and forested areas are more easily changed into cropland than more barren or wasteland areas, and similarly grassland is more likely to be turned into cropland than perhaps any other land use type (van Vliet et al. 2017; Gibbs et al., 2010; Zheng et al., 2019). There are major concerns about the loss of natural habitats and habitat fragmentation as a result of these changes at all scales. As well as direct expansion into what could be classed as natural habitat on the fringes of an urban area, urban expansion has knock on indirect displacement effects which may impact such habitats locally, regionally and globally (Ke et al., 2018).

The United Nations Human Settlements Programme (UN-Habitat) advocates compact cities to mitigate the negative impacts of urban expansion (Seto & Ramankutty, 2016). More compact cities accommodate more people, industry and everything that makes up the urban fabric within a smaller urban area footprint than a less compact, more sprawling city. Cropland Protection Policies (CPP) have been introduced in some densely populated parts of the world, to both restrict urban area expansion and encourage agricultural production in urban areas and their periphery. In recent years, the Japanese government enacted cropland protection laws to protect cropland directly, and also placed restrictions on the imports of primary agricultural products to increase the price of locally produced agricultural products which has had the effect of protecting cropland indirectly (Monk et al., 2013). In western European countries cropland is protected by: planning restrictions; delineating priority areas for cropland; and, setting targets to control cropland loss (Oliveira et al., 2019).

For the last 30 years or more, there has been rapid urbanization in China. In 2017 it was estimated that 58.52% of the population lived in urban areas (National Bureau of Statistics of China, 2018). Whilst the total population of China is unlikely to change much in the next decade, the proportion of people living in urban areas is expected to rise to around 70% by 2030 (United Nations, 2018). In response to concerns about food security, various CPP have been implemented in China. (Lichtenberg & Ding, 2008).

There are natural language translation difficulties when considering land use and policy terminology. The meanings of farmland, cropland, cultivated land and natural habitat are different in different contexts. In the Chinese context, cropland, which is protected by CPP, commonly refers to areas planted with high yielding cereals: including drier tilled land used to grow wheat and barley; and, wet paddy fields where the main crop is rice. Cropland in this context may also include land where vegetables are grown but is typically not where fruit is grown (Xin & Li, 2018).

Among various CPP enacted in China, the Cropland Supplement Policy (CSP) applies when urban land expands into cropland. In general, the CSP aims to ensure that overall the amount of cropland area is maintained at the province level, thus cropland changed to urban land use is replaced by other land changed to cropland (via land development, land consolidation, land rehabilitation, or agricultural restructuring projects). The CSP mainly involves cropland supplement via land development projects, which typically results in natural habitats being converted into cropland (Wu et al., 2017). In this study, natural habitat refers to forest, grassland, wetland, open water, and unused lands (IUCN, 2013; Ke et al., 2018).

The CSP in China has been variously studied. Song & Pijanowski (2014) revealed that in the whole of China "the total gained cropland by land exploitation, consolidation and rehabilitation" from 1999 to 2008 was 27,677 km2 and the "the total lost cropland by construction occupation" was 21,011 km2. Yet in this period, the total cropland area reduced by around 6% (Song & Pijanowski, 2014). Feng et al. (2015) and Song & Pijanowski (2014) contend that the displacement of cropland as a result of the CSP can lead to productivity decline and ecosystem degradation, and Chen et al. (2019) revealed that newer cropland is generally less productive. Academic study has also focused on the trade-off between changes of Ecosystem Services Value (ESV) and changes of potential productivity of supplemented cropland (Zheng et al., 2018); and the amount, heterogeneity, and patterns of supplemented cropland (Liu et al., 2019). Although historical impacts of the CSP on ESV have been estimated in several studies (Chen et al., 2019), few of them identified the impacts of the CSP from other related policies, in particular the Grain to Green Project, implemented during the same period (Wang et al., 2017). This study begins to address a need for investigating the likely future impacts of the CSP on local ecosystem services, which is arguably essential for any adaptive and forward looking policy appraisal.

Given the landscape diversity and the CSP implementation context (will be illustrated in Section 2.2), herein a case study of Hubei Province in China, which investigates the impacts of the CSP on land use changes in associated with ESV variations during the periods 2000-2015 and 2015-2030 is examined. It presents results of a modelling exercise which explores the differences of both land use changes and ESV changes under a couple of different policy scenarios: a scenario with Loose Cropland Protection (LCP) and a scenario with Strict Cropland Protection (SCP). By comparing the differences of land use and ESV changes between two scenarios, some impacts of the CSP are identified.

## 2. Methodology and Data Source

### *2.1. Research framework*

In order to investigate the impacts of the CSP on land use changes and ecosystem services, the study was divided into two parts (Figure 1). The first step was to examine observed land use changes across the study area between 2000 and 2015. As the CSP was introduced in 1998 in Hubei Province, observed land use changes were under the influence of the CSP, thus a possible way to investigate the impacts of the CSP on land use change is to compare observed land use changes and simulated land use changes without the CSP influence. However, the CSP was not the only policy or change influencing observed land use changes, the *Grain for Green Project* and major water reservoir construction projects also had a significant influence on land use change during this period. Thus, in order to identify the impacts of the CSP, two contrasting policy scenarios were developed: the *Strict Cropland Protection* (SCP) scenario and *Loose Cropland Protection* (LCP) scenario. Under the SCP scenario, the CSP applied, any loss of cropland resulting from urban expansion was to be supplemented somewhere else in the province to keep the area of cropland constant; whereas under the LCP scenario, any cropland loss due to urban expansion was not required to be supplemented. The LANDSCAPE model was applied to simulate the land use changes in the period 2000 to 2015 under both scenarios. Thus, the influence of the CSP on land use changes could be examined by comparing the simulated land use from 2000 to 2015 under both LCP and SCP scenarios. Then, the impacts of the CSP on ecosystem service associated with land use change can be translated into ESV differences by using an equivalent factor method.

Based on a number of assumptions, land use change under the two scenarios was simulated for the period 2015 to 2030. Again these changes were translated into estimated changes in ESV to suggest the ecological impacts of the CSP under the different scenarios in the next ten years.

*[Insert Figure 1 here]*

Figure 1. Research framework

### *2.2. Study area and data sources*

Located in the central China, Hubei Province covers an area of 185,900 km$^2$. Altitude varies from less than 60m to more than 1800m above sea level. The western, northern and eastern parts of the province are mountainous areas dominated by forest and grasslands; the central and southern parts are lake plains covered by cropland, wetlands, and urban land (Figure 2). Since the CSP has been implemented in the province (over the last 20 years), many areas of natural habitat have been converted into cropland (Tang *et al.,* 2020). More areas of natural habitat are expected to be converted in the future if the same CSP remains.

*[Insert Figure 2 here]*

Figure 2. Land use of Hubei Province in China, 2015

The data employed in the study are listed in Table 1. These include land use, terrain, accessibility, soil, climate, and socio-economic data.

Table 1. Data Source: (Ke *et al.,* 2018)

*[Insert Table 1 here]*

Land use data for Hubei Province are derived from Landsat TM images, and the overall accuracy is estimated to be above 90% in general at a spatial resolution of 30 meters (Liu *et al.*, 2005). For this study, the land use maps original twenty-five classes were reclassified to eight primary land use types (Table 2).

Table 2. Land-use reclassification for Hubei Province, China Source: (Liu et al., 2005)

*[Insert Table 2 here]*

The digital elevation model (DEM) has a resolution of 90 meters. Slope was calculated from the DEM data. Soil data were obtained at a scale of 1:1,000,000. And, following Tang *et al.,* (2020), the average annual cumulative temperature and annual precipitation for the period 1990 to 2010 were interpolated from sample points to the surface by applying Kriging approach. The absolute errors of interpolation of the average annual accumulated temperature and annual precipitation were 0.20° C and 2.15 mm, respectively. Soil data and climate data were used to evaluate agricultural suitability in the LANDSCAPE model. Accessibility was estimated based on road network data, which was extracted from the Traffic Atlas of Hubei Province (Table 1). The road network was used to generate a Euclidean distance surface, which is used as a proxy for accessibility. All the spatial datasets were converted to raster format with a resolution of 100 meters for use in the LANDSCAPE model.

### *2.3 The LANDSCAPE model*

The LANDSCAPE model is a cellular automata (CA) model (Ke *et al.*, 2017; Ke *et al.*,2018), which represents the study area as a regular gird of cells each with a single (dominated) type of land use. In the LANSCAPE model, land use types are classified into active or passive types, which are determined by the relationship between land use and human demand (Ke *et al.,* 2017). Changes in the area of active land use types are specifically driven by demand, for example demand for new residential areas. In contrast, changes in the area of passive land use types are driven by changes in the area of active land use types (e.g., urban areas can expand into grassland areas, but grassland areas will not expand into urban areas). The simulation of land use change is controlled by the probability of transition (POT), which is the probability of occurrence of a target land-use type on any cell. The POT is derived from the suitability of each land use type and the resistance to change of the existing land use type, formulated as Eq.(1):

$$POT_{j,eu,ou} = \frac{P_{j,ou}}{R_{j,eu}} \quad (1)$$

where $POT_{j,eu,ou}$ represents the probability that a cell *j* will transform from the existing land use type *eu* into the objective land use type *ou*; $P_{j,ou}$ refers to the suitability of land use type *ou* at cell *j*; $R_{j,eu}$ refers to the resistance to change of the existing land use type *eu*, which represents the likelihood of cell *j* being converted from the existing land use *eu* to any other land-use type.

Suitability $P_{j,ou}$ for a cell at location *j* is calculated as in Eq.(2):

$$P_{j,ou} = (1 + (-\ln r)^{\alpha}) \times PG_{j,ou} \times Con(C_{j,ou}) \times \Omega_{j,ou} \quad (2)$$

where *r* is a stochastic pseudo random number which is a value between 0 and 1 in the simulation; *α* is a dispersion factor that represents a random factor. $PG_{j,ou}$ is a factor that represents the likelihood of change to the objective land use type *ou* given a combination of biophysical and socioeconomic factors for the cell *j* including terrain suitability, accessibility, soil and climate factor. $Con(C_{j,ou})$ is a binary constraint variable, which indicates whether cell *j* is suitable for changing into a specific type of land use *ou* (1 for suitable and vice versa ). $\Omega_{j,ou}$ is the proportion of cells with the objective land use type *ou* among all of the cells in the neighbourhood(commonly a 3 × 3 window) of the cell *j*.

Resistance in Eq.(1) refers to transition difficulty from current land use type to other land use types, which indicates the degree of neighbourhoods of the original land use can be occupied by the target type of land use, and can be calibrated and formulated as Eq.(3) (Ke *et al*., 2017).

$$R_i = \frac{M_{max} - M_i}{M_{max} - M_{min}} \times (R_{max} - R_{min}) + R_{min} \quad (3)$$

where $R_i$ is resistance of land use type $i$, and $M_{max}$, $M_i$, $M_{min}$,represent the maximum, median, minimum of degree of neighborhood of land use type *i* occupied by other land use types. In the model calibration, the degree of neighbourhood will be estimated by historical land use changes of study area. $R_{max}$ and $R_{min}$ are upper and lower bound of resistance range, respectively, and in this study these values were set as 1.5 and 1.0 following Ke *et al*., (2017) and Tang *et al*.,(2020).

Once the parameters have been calibrated, the LANDSCAPE model will run iteratively with the given demand for each active land use type. The simulated change in land use of the study is then revealed iteratively year by year.

### *2.4 Evaluation of ESV changes*

ESV has been a popular topic in ecological research (Costanza *et al.,* 2014; Akber *et al.,* 2018). de Groot *et al.* (2012) outlines two types of approach to evaluate ecosystem services values: a so called *primary data based approach* which includes markets value method and travel costs method, and is often applied to evaluate a single type of ecosystem service; and, the *equivalent factor method* (Turner *et al.*, 2015), where ESV is assessed as the economic value per unit area of ecosystem via a *basic value transfer function* (Costanza *et al.,* 2014). Due to its extensive data requirements, the primary data-based approach is usually only employed on a small spatial scale. Therefore, given that this study is a relatively-large scale study, the equivalent factor method was employed with ESV calculated as in Eq.(4):

$$ESV = \sum_{f=1}^{n}(A_f \times VC_f) \quad (4)$$

where *ESV* is the ecosystem services value for the entire study area; *f* refers to the land use types; $A_f$ is the area of a land use type; and $VC_f$ is the economic value of ecosystem services per unit area of land use type *f*. The values for $VC_f$ used are given in Table 3.

Table 3. Economic value of ecosystem services per unit area of each land use type (CNY/km$^2$)

*[Insert Table 3 here]*

Each $VC_f$ value is taken from Xie *et al.,* (2017) and adjusted using agricultural net profit values of Hubei Province derived from social and economic data. Following Xie et al. (2017) and Song et al. (2017), the ESV of cropland was considered in this study in order to avoid underestimating the ESV at prefecture or provincial level.

## 2.5 Implementation of the LANDSCAPE model

### *2.5.1 Model calibration and validation*

The probability of transition (POT) is the key parameter to calibrate the LANDSCAPE model. In this study, eight different types of land use (Table 2) were identified in the model. For each land use type, the suitability was calculated by Eq.(2). Following Ke *et al.*, (2017), the C5.0 decision tree algorithm was applied to estimate $PG_{j,ou}$ based on the four spatial driving factors, including terrain, accessibility, soil condition, and climate factors (variables are listed in Table 1). The resistance was calculated based on Eq. (3) with land use changes between 2000 and 2015.

The validation of LANDSCAPE model involve comparison between simulated land use map and real land use map. In this study, we set the demands for each type of land use in LANDSCAPE model as the total area of each land use in 2015, then run the simulation from 2000 to 2015. The Kappa Simulation approach, which is a coefficient of agreement between the observed land use changes and the simulated land use changes (van Vliet *et al.*, 2011), was used to measure the goodness of fit between the simulated and actual land use map 2015. The value of Kappa Simulation varies between -1 and 1, where: 1 indicates perfect agreement; 0 indicates that the simulation is only as good as results would be expected from a random model; and, negative values indicate that the model is worse than random. In this research, the Kappa Simulation scores for all land use types for the best fitting model are shown in Table 4, they are all above 0 although for Grasslands the value is close to 0, suggesting an acceptable goodness-of-fit.

Table 4. Kappa Simulation scores for the model results

*[Insert Table 4 here]*

*2.5.2 Land use changes simulation with LANDSCAPE under different scenarios*

Urban land and cropland were set as active lands in the study as the urbanization process and the implementation of the CSP in Hubei province are effectively demand driven. The demand for urban land in 2015 was set as the observed area of urban land for both scenarios. Under the SCP scenario, the demand for cropland in 2015 was set strictly as the value in 2000; while under the LCP scenario it was set as open, the amount and distribution of cropland was revealed by the simulation process.

As for 2030, the demand for urban land was set equal (Table 5) under both scenarios, which was estimated via a simple exponential growth model with a static growth rate starting from 2015. The annual growth rate was set as the average growth rate of urban expansion in the period 2000 to 2015.

The demand for cropland between 2015 and 2030 was set the same way as the simulation for the period 2000 to 2015. With the SCP scenario, demand for cropland was set to be constant (as it was in 2015), and under the LCP scenario it was set open.

For the two periods of simulation (2000-2015 and 2015-2030), the location for rural settlements and water areas was set as constant under both scenarios to establish a baseline for comparison. Even though the area of water increased considerably during 2000–2015 in Hubei Province - due to large scale water reservoir construction (i.e., The Three Gorges Reservoir), the water area was set to be constant for simplicity. The demand for each type of land is shown in Table 5.

Table 5. The parameters applied for the land use scenarios

*[Insert Table 5 here]*

# 3. Results

## *3.1 Observed and simulated land use change 2000-2015*

Figure 3 shows the observed and simulated land use change in Hubei province in the period 2000 to 2015. In the real world, the total area of urban land and water expanded significantly (by 3099.78 $km^2$ and 3004.17 $km^2$ respectively) in the province during this time, while the area of cropland fell by 4682.51$km^2$ despite the CSP being in place. A considerable loss of natural habitat, including forest (667.92 $km^2$) and wetlands (704.63 $km^2$), is observed in this period. In the simulation, the urban area expanded at the same speed as observed, the changes of other types of land use vary. Under the LCP scenario, cropland area shrank by 1851.51 $km^2$, and the area of forest fell by 1006.56 $km^2$. Under the SCP scenario, the area of cropland remained as it was in the year 2000, but there were reductions in the areas of forest (2479.74 $km^2$) and wetland (437.87 $km^2$).

The considerable differences between the observed land use change and the simulated data under the SCP scenario suggests that urbanization and the CSP are not the only driving forces for land use change. In fact, the loss of cropland during this 15 years is mainly a consequence of the large scale water reservoir construction projects (i.e. the Three Gorges Project) and the *Grain for Green Project.* Neither of these projects required cropland supplement practice. The *Grain for Green Project* contributed to there being less forest loss overall in the observed land use compared with the simulations.

A comparison between the simulated land use changes under different scenarios (i.e. SCP vs. LCP) offers a way to investigate the impacts of the CSP in terms of land use change and ecosystem services value (ESV) change.

*[Insert* Figure 3 *here]*

Figure 3. Observed and simulated land use changes in the period 2000 to 2015 in the Hubei Province.

### *3.2 Ecological impact of cropland supplement policy during 2000-2015*

The impacts of the CSP on ecosystem can be revealed by comparing the land use changes and ESV changes under LCP and SCP scenarios. As shown in Figure 3, under the LCP scenario, the area of cropland decreased by 1851.51 $km^2$ in the period 2000 to 2015, whereas under SCP scenario, the area of cropland remains constant. Since large areas of more natural habitat were converted into cropland in the province, the total area of natural habitat fells to 107538.51$km^2$ in 2015 under the SCP scenario – an additional loss of 1847.50$km^2$. The estimated cost in terms of loss of ESV in financial terms is 19.53 billion CNY.

Figure 4 shows the differences of natural habitat areas between the LCP and SCP scenarios. The results show that the western part of Hubei Province, including Shiyan, Xiangyang, Yichang and Enshi, lost a significant amount more natural habitat than the eastern part of the province where higher population and urban expansion is observed.

*[Insert* Figure 4 *here]*

Figure 4. Natural habitats areas differences among prefectures in Hubei Province between LCP and SCP (2000-2015)

Figure 5 illustrates the non-urban land use changes under two scenarios (LCP and SCP) between 2000 and 2015 at prefecture level. This figure is in three parts. In parts a) and b): the horizontal axis represents the amount of land use changes, where a positive value indicates an area increase and negative value indicates an area loss; and, the results for each prefecture are shown as a bar.

The difference between Figure 5 a) and b), reveals a spatial effects of the CSP. Under the LCP scenario, the areas of most land use types decreases and cropland decreases in all prefectures. In Enshi, Shiyan and Yichang, the biggest change in land use is a reduction in forest area. These three prefectures are located in a mountainous area in the west of the province. The result for the more urban prefectures of Wuhan, Jingzhou, and Huanggang in the east is a considerable loss in cropland, account for more than 60% of the total loss of all land use types. These prefectures are located in the Jianghan Plain which is a major rice and other grain growing area.

Figure 5 b) shows that under SCP the results are that in some prefectures cropland will increase, but that overall the loss of forest land is huge. Wuhan is the prefecture that is likely to experience the greatest loss of cropland.

The difference between the LCP and SCP scenarios is shown in Figure 5 c). The main difference is that under SCP there is more cropland, but far less forest, wetland and grassland. But differences at the prefecture level are revealed with regard the proportion and relative amounts of change.

The model results are that in total: 1472.85 $km^2$ area of forest (mainly in Shiyan, Enshi, Yichang and Xiangyang); 99.94 $km^2$ of grassland (mainly in Enshi and Shiyan); and, 274.71 $km^2$ of wetland (mainly in Jingzhou, Wuhan and Huanggang) would become cropland under SCP for the period 2000 to 2015.

*[Insert* Figure 5 *here]*

Figure 5. Simulated change of non-urban land use type area by prefectures under two scenarios in the period 2000 to 2015 in Hubei Province.

### *3.3 Ecological impact of cropland supplement policy during 2015 and 2030*

This section presents the LANDSCAPE model results and the difference in ESV changes under the SCP and LCP scenarios from 2015 to 2030. Under the LCP scenario, the amount of cropland is modelled to decrease by 2108.32 $km^2$ between 2015 and 2030, the total amount of natural habitat is modelled to decrease to 110681.19$km^2$. Comparatively, under the SCP scenario, the amount of cropland remains constant, while the total amount of natural habitat is modelled to decrease to 108576.61$km^2$, suggesting an extra 2104.58$km^2$ loss of natural habitat compare to the LCP scenario. Figure 6 shows land use change under both scenarios by land use types. It shows that new cropland often replaces forest or wetland areas.

*[Insert* Figure 6 *here]*

Figure 6. Land use changes under LCP and SCP in the period 2015 to 2030 in the Hubei Province.

Under the LCP scenario, the total ESV of Hubei Province falls to 925.77 billion CNY by 2030, which is 11.13 billion CNY less than 2015. Under the SCP scenario, the total ESV decreases to 913.23 billion CNY in 2030, suggesting an additional 12.54 billion CNY loss during the period compared to the LCP scenario.

Figure 7 shows the spatial impact of the CSP at prefecture level. The model results are that natural habitats of central Hubei prefectures (i.e., Xiangyang and Jingmen) will experience the greatest loss of natural habitats under the SCP compared with LCP.

*[Insert* Figure 7 *here]*

Figure 7. Natural habitats areas differences between LCP and SCP (2015-2030) in the Hubei Province

Figure 8 shows the area changes of non-urban land use types at prefecture level during 2015-2030. Under LCP scenario (illustrated in Figure 8 a), the area of cropland drops in all prefectures. Four prefectures account for more than 50% of the total cropland loss, which are Wuhan (471.01 $km^2$), Huangggang (257.87 $km^2$), Jingzhou (192.89 $km^2$), and Jingmen (151.93 $km^2$). Figure 8 b) shows the land use changes by prefecture under SCP scenario, where considerable increase in cropland area can be expected in Xiangyang (129.56 $km^2$), Shiyan (126.84 $km^2$), Jingmen (86.94 $km^2$) and Enshi (60.70 $km^2$). Overall under SCP, there is a loss of more natural habitat (i.e., 1560.44 $km^2$ of forest, 89.6 $km^2$ of grassland, 454.54 $km^2$ of wetland). Figure 8 c) makes the details about these differences between the two scenarios clearer. The major differences under SCP compared with LCP are an extra loss of wetland area in Jingzhou (97.90$km^2$) and extra losses of forest in Huanggang (208.44km$^2$), Jingmen (209.19km$^2$) and Xiangyang (224.60km$^2$).

*[Insert* Figure 8 *here]*

Figure 8. Simulated changes of non-urban land use type area by prefecture under two scenarios in the period 2015 to 2030 in Hubei Province

Figure 9 shows the loss of the natural habitat as a proportion of the total land area at prefecture level in 2015. The results suggest that Qianjiang would lose more than half of its forest and all of its grassland, Tianmen and Xiaogan would lost more than half its grassland under SCP.

*[Insert* Figure 9 *here]*

Figure 9. The proportion of natural habitat loss during 2015-2030 against the level of 2015 in the Hubei Province

## 4. Discussion

Given food security concerns and considering increasing demand for food and agricultural produce generally, cropland reclamation could be vital for countries with large and growing populations. Many countries undergoing large scale and rapid urbanization with scarce cropland resources have adopted CPP to maintain the quantity and/or quality of cropland. Many countries in central Asia, South America and Africa are experiencing cropland expansion (Liu *et al.,*2018; Zabel *et al.,* 2019). Even though cropland reclamation is a feasible option to meet future demand for food and agricultural production, it is believed that cropland reclamation in association with urbanization comes at the cost of natural habitat loss and ecosystem degradation (Zabel *et al.,* 2019). It is essential for planners and stakeholders to further understand the spatial spill-over effects of cropland reclamation practice and minimize the trade-off between crop production and ecosystem protection.

Land use change as a result of rapid urban expansion does not have to pose negative impacts in terms of agricultural productivity and ecosystems in general, but in practice this is often the case. There is a legitimate concern and a need for wide reaching consideration and analysis of policy and potential policy impacts at all scales. Given the complex nature of spatial process, the advent of modern spatial simulation techniques (i.e. Cellular Automata) offers a way to help understand spatial impacts of policy. This paper demonstrated that the LANSCAPE model offers a feasible framework that is beneficial for policy maker and stakeholders around the world to design local policy or assess the ecological effects proactively. The framework can be employed to develop "what-if" scenarios to assess the long-term consequences of different land use policies associated with urban expansion in terms of changes in ESV.

In China, since early 2000, the CSP has been implemented in an attempt to maintain agricultural productivity and food production capability. Although the CSP has been largely successful in maintaining cropland area in the face of rapid urbanization, Song & Pijanowski (2014) revealed that in general productivity is lower in the newly created cropland areas, and Chen *et al.* (2019) raised concerns that the CSP contributed to widespread ecosystem degradation. Whilst these and other previous studies, such as Xin & Li (2018), highlight some of the general issues of the current CSP implementation, few studies have investigated the impacts spatially in the way done in this study. By adopting a scenario based simulation approach, this study not only identified impacts of the CSP on regional ecosystem service from a series of land use related policies implemented at the same time, but also quantified the potential impact of the CSP on ecosystem service in the future.

A series of reforms have been proposed that aim to balance the productivity of cropland in China (Lu *et al.,* 2017). The impacts of these reforms at prefecture and provincial levels should be investigated as they are likely to lead to a detrimental loss of ecosystem services in some places adversely impacting human health and well-being. According to the “ecological civilization construction” strategy promoted by the Chinese government, the ecological (and social) impacts of the CSP shouldn’t be ignored in implementation (Lu *et al.,* 2017). This paper adds to the call for the development of a comprehensive cost, benefit and risk assessment framework for evaluating the CSP and for use as a policy making instrument.

Some simplifying assumptions were made in the study to cope computationally with the demands of the LANDSCAPE model. In particular, the mechanism of land use change was simplified as a probability function in the modelling process. The land use type with the highest conversion probability is the priority for grid cell allocation. However, similar to previous land use changes simulation models, such as FLUS (Liu *et al.*, 2017), the probability function is widely accepted for the land use change simulations. And, the simulated amount of cropland area of 2015 for both scenarios were higher than the observed cropland area in 2015 mainly due to the extra cropland acquisition for construction of the water reservoirs, which is not considered in the model. Additionally, natural protected areas are not considered, due to lack of accurate and available data.

The area based equivalent factor approach applied in this study also introduces uncertainty into the ESV evaluation. The uniform equivalent factor method ignores the spatial heterogeneity in ecosystem service for each type of land use, and does not take the spatial patterns (e.g. natural habitat fragmentation etc.) into consideration. The difference in ESV between newly reclaimed cropland and those mature cropland areas was ignored in this study, as the maturation period for newly reclaimed cropland is assumed to be relatively short within the simulated period. This simplification may tend to slightly underestimate the impact of the CSP on ecosystem service, however it does not change the main conclusion since the expected reduction in ESV is large anyway.

The ESV for urban land was set as zero in this study, although in reality urban land can also provide some ecosystem services. Yet, there is a lack of in-depth understanding and robust approach to evaluation of ecosystem services of urban land (Yi *et al.*, 2017). From the provincial or even larger scale policy perspective, it is reasonable to ignore the ESV provided by urban land as those values are cumulatively small compared with those of cropland and natural habitats.

The spatially explicit nature of the LANDSCAPE model provides flexibility and takes the spatial heterogeneity of land use into consideration, to evaluate the impact of any land use policy on ecosystem service in the future. For cropland protection purposes, a more comprehensive evaluation framework is wanted to help policy-makers and stakeholders further understand the spatial impact of CPP on habitat quality, carbon storage and biodiversity as well as on ESV. The simulation based policy appraisal framework demonstrated in this study provides a good foundation for future policy optimization practice which aims to minimize the trade-off between the crop production and ecosystem protection.

## 5. Conclusions

By taking Hubei province as a case, this study identified and quantified negative impacts of the CSP on natural habitats and ecosystem service under urban expansion by comparing simulated land use change under two different policy scenarios (known as

LCP and SCP). The results suggest that not only urban expansion but also the CSP threatens ecosystems in the study area. The differences of ESV changes in the simulated results under both scenarios indicates how much of an effect the CSP can have at different levels. There are significant differences in the expects loss of natural habitat in the prefectures of Hubei Province under the two scenarios, and a general significant loss of natural habitat for the province as a whole under both. During the period 2000 to 2015, about 1847.50 $km^2$ of natural habitat was replaced by new cropland, and this is associated with a total 19.53 billion reduction in ESV. In the period 2015 to 2030 it is estimated that the current CSP implementation will require 2104.58 $km^2$ of natural habitat to be replaced with new cropland, and this may lead to an additional loss of 12.54 billion CNY of ESV if rapid urban expansion continues as predicted. Additionally, due to the spatial heterogeneity of the land use, prefectures of Hubei Province will meet various degrees of ecosystem degradation risk under the influence of the CSP. For instance, even though the total area of forest and grassland are not that high in Qianjiang, Xiaogan and Tianmen, the high percentage loss of this natural habitat might result in worse degradation of the already fragile ecosystems in these areas.

This research reveals that implementation of the CSP in rapidly urbanizing areas has significant effects on the ecosystem services value. Decision-makers should not ignore the spatial differences of ecological impacts in economic decisions or land use planning practice. Given the negative effects of the CSP, more sophisticated policies should be proposed to balance economic growth, food security and maintain ecological balance and avoid the further environmental degradation especially of very fragile areas.

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Table 1. Data Source: (Ke *et al*., 2018)

| Dataset | Variables | Data Source |
| --- | --- | --- |
| Land use data | Land use 2000 | Resource and Environment Data Cloud Platform, Chinese Academy of Science |
| | Land use 2015 | |
| Terrain data | Elevation | The Shuttle Radar Topography Mission (SRTM) |
| | Slope | |
| Accessibility data | Euclidean distance to the nearest railway | The Traffic Atlas of Hubei |
| | Euclidean distance to the nearest highway | |
| | Euclidean distance to the nearest state road | |
| | Euclidean distance to the nearest provincial road | |
| | Euclidean distance to the nearest main road | |
| | Euclidean distance to the nearest county road | |
| Soil data | Soil pH value | The China Soil Database |
| | Effective soil depth | |
| | Soil organic matter content | |
| | Soil phosphorus | |
| Climate data | Average annual cumulative temperature | Chinese Meteorological Administration |
| | Annul precipitation | |
| Socio-economic data | Net profits of agricultural products | National Agricultural Statistics 2016 |
| | Planting areas of rice, wheat and maze | Hubei Provincial Statistical Yearbook 2016 |

Table 2. Land-use reclassification for Hubei Province, China Source: (Liu *et al*., 2005)

| Land-use reclassification | Sub-classes of land-use |
|---|---|
| Cropland | Paddy land, and Dry land |
| Forest | Forest, Shrub, Woods, and Others |
| Grasslands | Dense grass, Moderate grass, and Sparse grass |
| Water area | Stream and rivers, Reservoir and ponds, and Lakes |
| Wetlands | Permanent ice and snow, Beach and shore, Bottomland, and Swampland |
| Urban land | Urban built-up,<br>Industrial, mining and transportation construction |
| Rural settlement | Rural settlement |
| Unused land | Sandy land, Gobi, Salina, Bare soil, Bare rock, and Others |

Table 3. Economic value of ecosystem services per unit area of each land use type (CNY/$km^2$)

| Land use types | Cropland | Forest | Grasslands | Water area | Wetlands | Unused land |
|---|---|---|---|---|---|---|
| Equivalent value | 958,061 | 5,583,432 | 3,778,882 | 30,466,329 | 12,641,550 | 48,509 |

Table 4. Kappa Simulation scores for the model results

| Land use types | Cropland | Forest | Grasslands | Wetlands | Urban land | Rural settlement | Unused land |
|---|---|---|---|---|---|---|---|
| Kappa Simulation | 0.105 | 0.026 | 0.008 | 0.186 | 0.307 | 0.037 | 0.101 |

Table 5. The parameters applied for the land use scenarios

| | 2000 | 2015 | SCP (2030) | | LCP (2030) | |
|---|---|---|---|---|---|---|
| | Area ($km^2$) | Area ($km^2$) | Demand ($km^2$) | Resistance | Demand ($km^2$) | Resistance |
| Cropland | 69598.07 | 64915.56 | 64915.56 | 1 | - | 1 |
| Forest | 92468.27 | 91800.35 | - | 1.25 | - | 1.25 |
| Grasslands | 7005.37 | 6815.35 | - | 1.25 | - | 1.25 |
| Water area | 6349.98 | 9354.15 | - | 1.5 | - | 1.5 |
| Wetlands | 4771.14 | 4066.51 | - | 1.25 | - | 1.25 |
| Urban land | 1487.3 | 4587.08 | 8054.95 | 1.5 | 8054.95 | 1.5 |
| Rural settlement | 3648.55 | 3796.61 | - | 1.5 | - | 1.5 |
| Unused land | 52.87 | 45.94 | - | 1 | - | 1 |

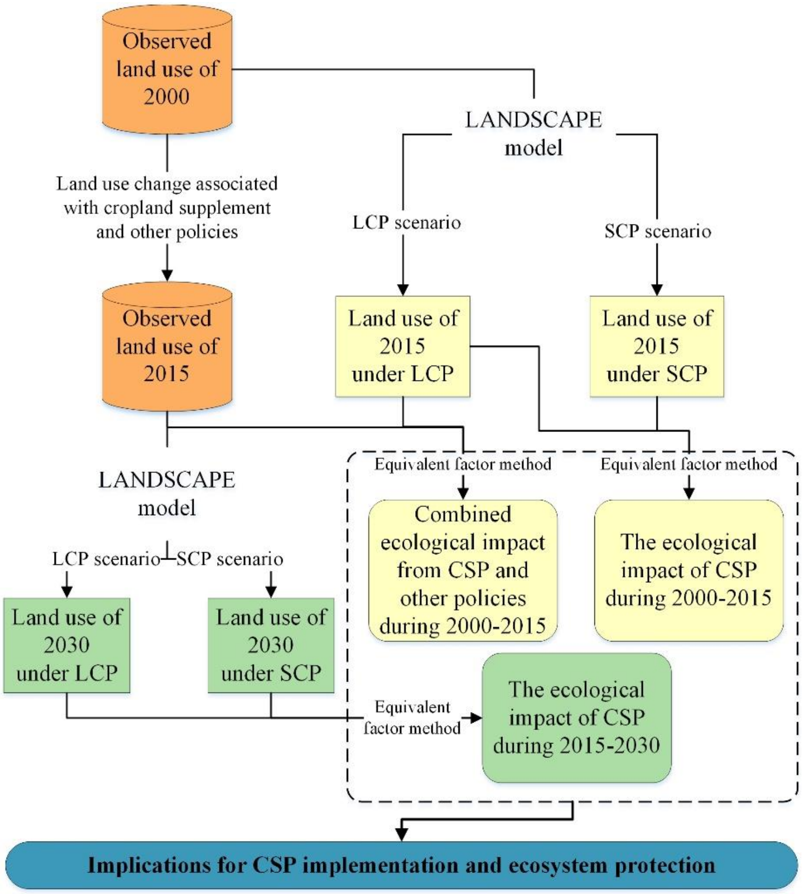


Figure 1. Research framework

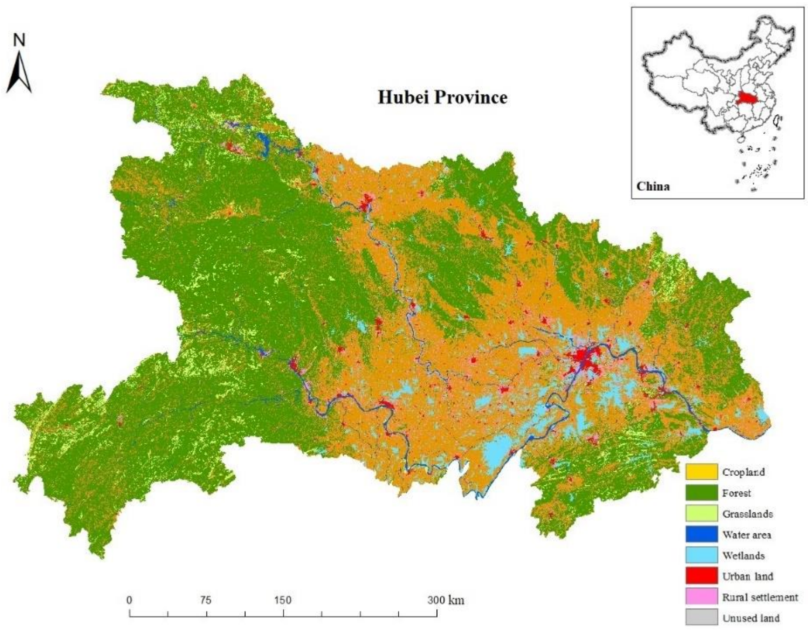


Figure 2. Land use of Hubei Province in China, 2015

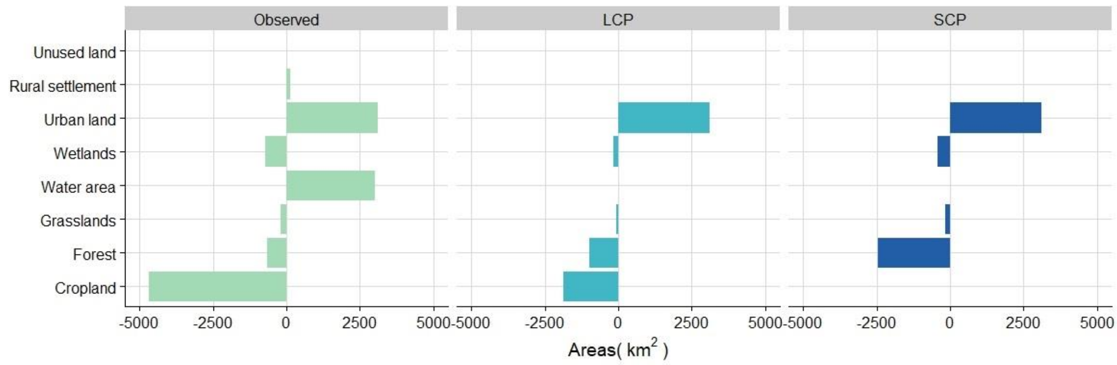


Figure 3. Observed and simulated land use changes in the period 2000 to 2015 in the Hubei Province.

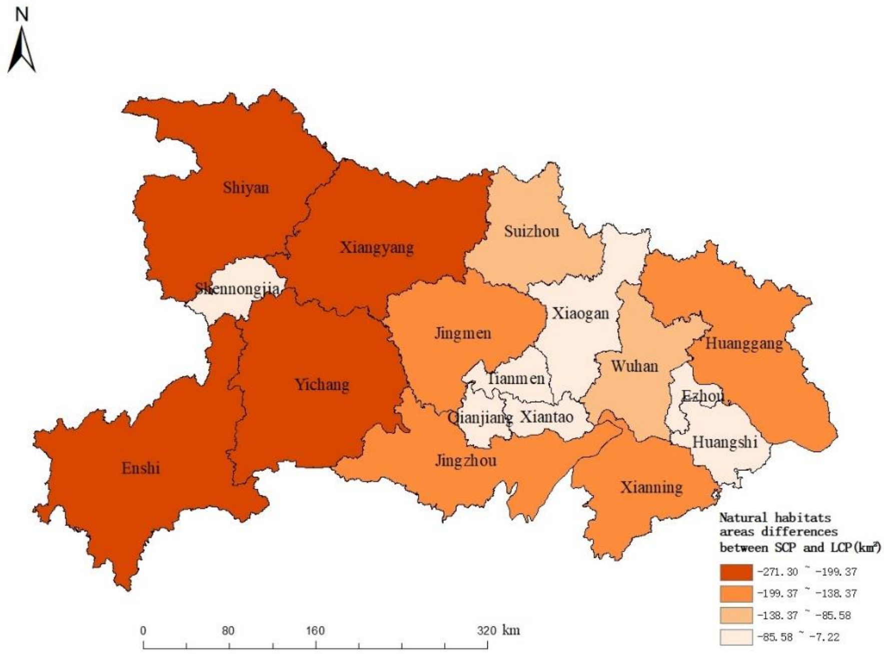


Figure 4. Natural habitats areas differences among prefectures in Hubei Province between LCP and SCP (2000-2015)

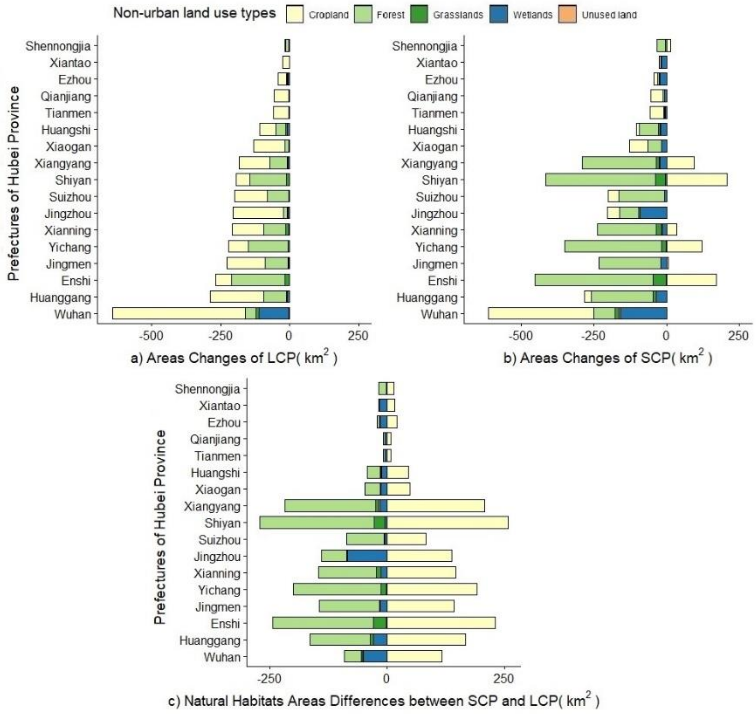


Figure 5. Simulated change of non-urban land use type area by prefectures under two scenarios in the period 2000 to 2015 in Hubei Province.

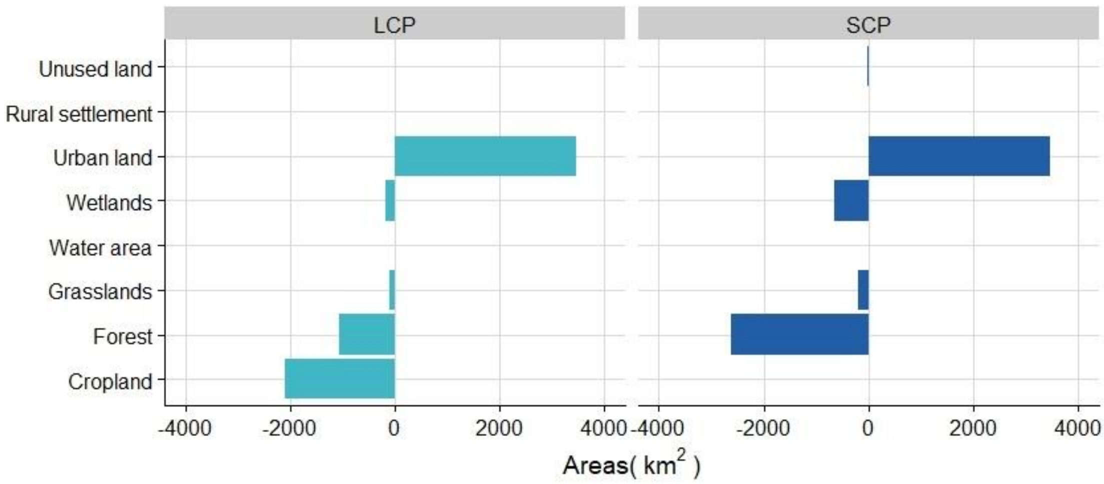


Figure 6. Land use changes under LCP and SCP in the period 2015 to 2030 in the Hubei Province.

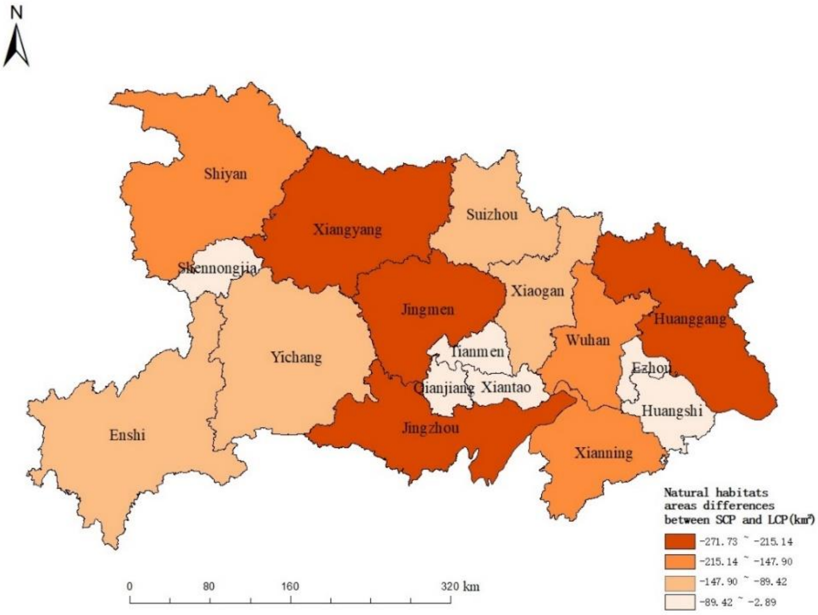


Figure 7. Natural habitats areas differences between LCP and SCP (2015-2030) in the Hubei Province

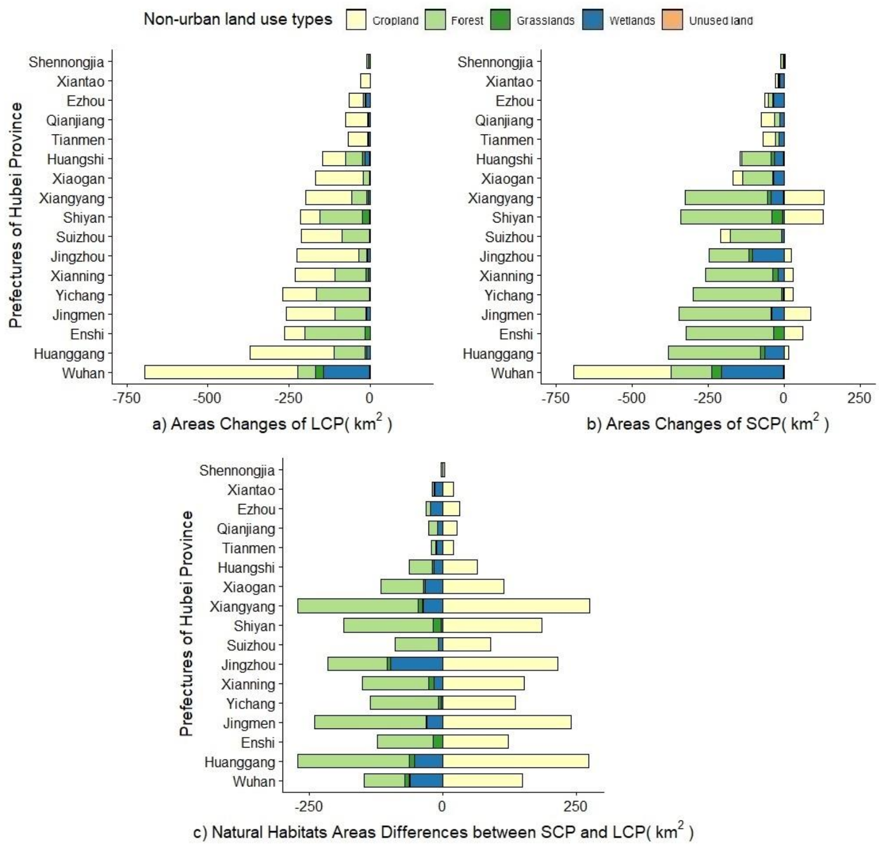


Figure 8. Simulated changes of non-urban land use type area by prefecture under two scenarios in the period 2015 to 2030 in Hubei Province

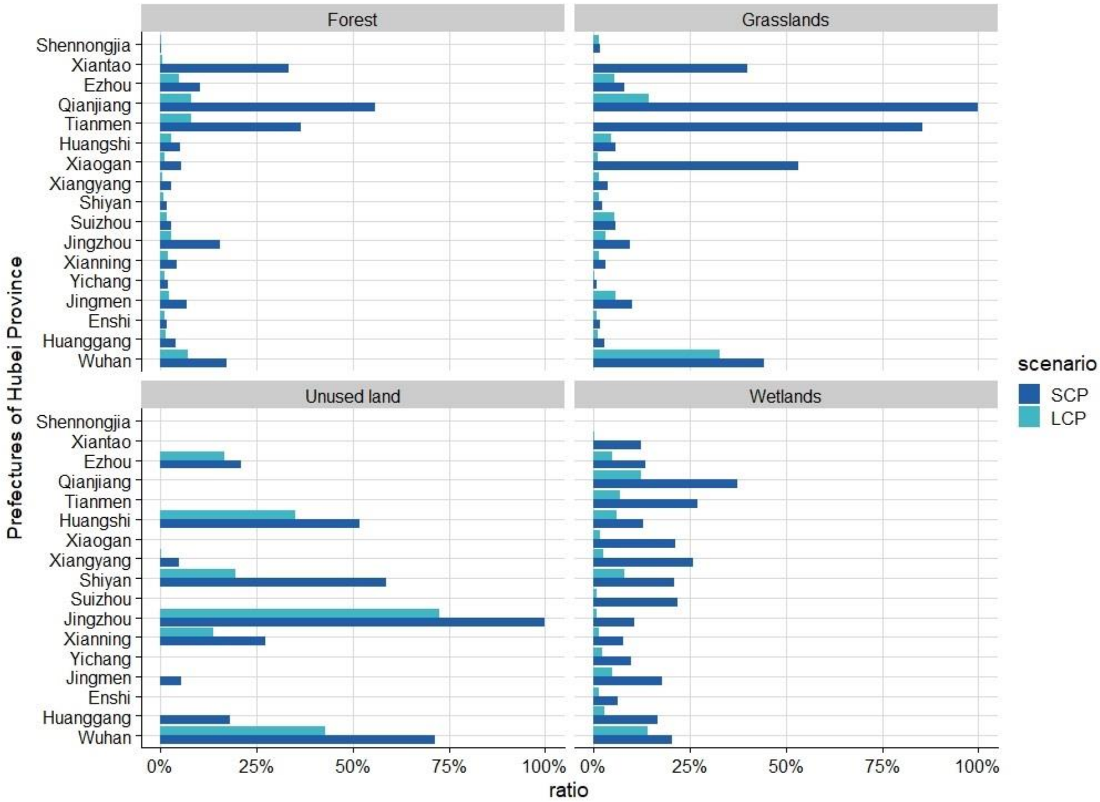


Figure 9. The proportion of natural habitat loss during 2015-2030 against the level of 2015 in the Hubei Province