

## Research Paper

# GlobeLand30 shows little cropland area loss but greater fragmentation in China



Qiangyi Yu<sup>a,b,\*</sup>, Qiong Hu<sup>a,1</sup>, Jasper van Vliet<sup>b</sup>, Peter H. Verburg<sup>b,c</sup>, Wenbin Wu<sup>a,\*</sup>

<sup>a</sup> Key Laboratory of Agricultural Remote Sensing (AGRIRS), Ministry of Agriculture/Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, China

<sup>b</sup> Environmental Geography Group, Institute for Environmental Studies (IVM), Vrije Universiteit Amsterdam, Amsterdam 1081HV, The Netherlands

<sup>c</sup> Swiss Federal Institute for Forest, Snow and Landscape (WSL), Birmensdorf, Switzerland

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## ABSTRACT

Understanding of cropland dynamics in a large geographical extent is mostly based on observations of area change, while the changes in landscape pattern are hardly assessed. The total amount of cropland in China has remained relatively stable in recent years, which might suggest there was little change. In this analysis, we combine the number of cropland patches (NP) with the total cropland area (TA) for a more comprehensive characterization of cropland change in China. We use GlobeLand30—a global land cover dataset with a 30 m resolution for the years 2000 and 2010—and characterize changes in TA and NP for each county as increase, stable, or decrease. This characterization shows that 703 out of 2420 counties experienced both cropland loss and increased fragmentation. The predominant cropland loss in these areas, especially in the North China Plain, is converted to artificial land. Another 212 are characterized by the opposite developments: an increase in cropland and decreased fragmentation. These counties, are mainly characterized by a conversion of forest areas and grassland areas. It suggests that the cropland conservation policy in China effectively protected the total cropland area in overall, but the consequences in terms of fragmentation might be underestimated. Counties with no obvious change in both indicators, measuring 279 counties, are mainly located in the Southeast. Our results are further compared with local level case studies: the fair consistency indicates alternatives of applying GlobeLand30 for analyzing landscape changes across scales and for cross-site comparisons.

## 1. Introduction

Cropland is vital for human as a producer of food, fuel, fibers, and many other ecosystem services. It is the largest use of land on the planet and it is one of the most important land cover types for society (Foley et al., 2011). Cropland is also an essential research topic for land system studies (Verburg et al., 2013) and landscape studies (Merriam, 1988), where the spatial-temporal characteristics of cropland has been assessed from local level to global level. Land system science mainly focuses on the area of cropland cover, and the existing analyses include area expansion and conversion (Döös, 2002; Tyler et al., 2015), abandonment (Schierhorn et al., 2013), displacement (Meyfroidt et al., 2010; van Vliet et al., 2017), and potential availability (Lambin et al., 2013; Eitelberg et al., 2015). Recently, more attention is given to the spatial structure of croplands in terms of farm size (Samberg et al., 2016), field size (Fritz et al., 2015) or the level of fragmentation of

cropland area with other land use types (van der Zanden et al., 2013). Usually, cropland area change is often considered in the context of climate change, food security, and sustainability at a macro level (Verburg et al., 2015), while fragmentation is frequently connected with detailed placed-based ecological and social processes at a micro level, e.g. distribution, movement, and persistence of species (Forman and Godron, 1986; Turner, 1989).

In China, the spatial-temporal characteristics of cropland and their consequences, among other land cover types, have gained much attention from scientists and policy-makers. This is because Chinese cropland plays an essential role as the “rice bowl” for the country, which currently feeds 22% of the world population with only 7% of the planet's cropland resources (Ryan and Flavin, 1995). Especially since the late 1990s, the challenge to provide national food security has been amplified along with China's unprecedented economy growth. A national level land cover mapping work suggests a net cropland loss of

\* Corresponding authors at: Key Laboratory of Agricultural Remote Sensing (AGRIRS), Ministry of Agriculture/Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, China.

E-mail addresses: [yuqiangyi@caas.cn](mailto:yuqiangyi@caas.cn), [q.y.yu@vu.nl](mailto:q.y.yu@vu.nl) (Q. Yu), [wuwenbin@caas.cn](mailto:wuwenbin@caas.cn) (W. Wu).

<sup>1</sup> Co-first author of this work.

0.69 million ha from year 2000 to 2005 (Liu et al., 2010), then followed by a loss of 0.15 million ha from 2008 to 2010 (Zhang et al., 2014). Together, cropland has roughly decreased about 1.02 million ha in the first decade of the 21th century (Liu et al., 2014a). Such an area loss is believed to have large impacts on food security (Shi et al., 2013; Kong, 2014; He et al., 2017) and on other ecosystem services (Lü et al., 2012; Liu et al., 2012; Wu et al., 2013; Peng et al., 2017a). However, those assessments only included area change, without considering changes in landscape pattern.

Net area changes in land cover inevitably lead to changes in landscape pattern (Nagendra et al., 2004). For example, the recent changes in land use/cover in the Dhaka Metropolitan area of Bangladesh – represented by a large reduction of cropland and wetland – have resulted a highly fragmented landscape as a result of rapid increase in the built-up areas (Dewan et al., 2012). Similar analyses can also be found for China, e.g. cropland fragmentation in South Jiangsu Province (Cheng et al., 2015) and in Northwest Zhejiang Province (Su et al., 2014). However, the interaction between gross area changes and landscape pattern has remained largely unexplored. We hypothesize that landscape fragmentation might be amplified owing to the relocation of land cover, because even when the net changes remain insignificant, the gross changes might far exceed net changes (Fuchs et al., 2015).

Such concerns raise the necessity of re-assessing cropland change in China, given the net loss only accounts to 0.72% of the total cropland area between 2000 and 2010 (Liu et al., 2005; Liu et al., 2014a). Since China has little scope for further cropland expansion (Kong, 2014; Wu et al., 2014), it is adopting a very strict cropland conservation policy, e.g. the “increasing vs. decreasing balance” policy (Liu et al., 2014b), aiming for a stable amount of cropland area in the long term. However, a constant amount of cropland does not necessarily prevent any changes in the landscape pattern. Until recently, an analysis of landscape pattern for the whole of China was challenging, because it would require the classification of a large number of remotely-sensed images at a fine resolution. The recent release of GlobalLand30 – the first global land cover datasets at a 30 m resolution (Chen et al., 2015) – provides an alternative for such a reassessment. Based on GlobalLand30 data in the year of 2000 and 2010, this paper aims to develop a new characterization of cropland change that combines both area and structure for all counties in China. Subsequently, we assess what manifestations of cropland change are related to specific combinations of area change and changes in fragmentation, in order to relate observations with observed land change processes. In addition, we compare these findings with existing local level case studies and discuss these cropland changes in the context of related cropland use policies in China.

2. Materials and methods

2.1. Land cover data

GlobeLand30 is the world’s first global land cover dataset at a 30 m resolution (Chen et al., 2014). The GlobeLand30 datasets were extracted from more than 20,000 Landsat and Chinese HJ-1 satellite images and comprise ten land cover types for the years 2000 and 2010 (Chen et al., 2015). Details of the land cover data can be found at <http://www.globallandcover.com>. This relatively high spatial resolution and wide spatial coverage provide the possibility of measuring the characteristics of cropland in the whole of China. Both datasets, i.e. for 2000 and 2010, are used in this study.

2.2. Characterization of cropland change

We characterize cropland changes by a combination of two indicators, which measure the changes of land cover and landscape pattern, respectively. Changes in land cover are assessed based on the total area (TA), as it is a widely used indicator for the (net) land cover change between two time points. Changes in landscape pattern are

assessed based on the number of patches (NP), which is part of a larger family of landscape indicators introduced from the field of Landscape Ecology (Turner, 1989; Li and Wu, 2004). Given that the purpose of this study is to observe the changes of landscape pattern along with the process of land cover change – rather than measuring the comprehensive characteristics of landscape pattern – we did not include a larger range of pattern indices available. NP was selected as Taylor et al. (1993) believed that connectivity is the vital indicator for reflecting landscape fragmentation: more patches in a given area means a weaker connectivity thus the landscape is more fragmented.

Spatial land cover data are analyzed at a county-level basis. The calculations of TA and NP are based on FRAGSTATS (McGarigal and Marks, 1995). The characterization of cropland change combines TA and NP to represent different types of cropland change. For each indicator, three intervals have been applied and recognized as “decreased”, “stable” and “increased”, respectively. A histogram-based approach is applied to measure the distribution of the TA and NP changes at the national level. The bin width is subsequently set following the Freedman-Diaconis rule (Freedman and Diaconis, 1981):

$$H = 2 \times IQR \times N^{-1/3}$$

where  $H$  is the bin width, IQR is the interquartile range of the data, and  $N$  is the number of observations in the sample. All the calculations are based on the percentages change for TA and NP, respectively.

According to the histogram-based approach, the bin width  $H$  for TA and NP are estimated as 0.5% and 4.5%, respectively. The two intervals at either side of 0 are both considered stable, which means that a county with TA change above 0.5% is classified as an increase in total cropland area, a value below -0.5% is classified as a decrease, while any value between -0.5% and 0.5% is classified as stable. A similar classification scheme is applied for NP, but the thresholds for this value are  $\pm 4.5\%$ . Consequently, nine groups have been identified, to represent the different characterizations of cropland change considering the combination of TA and NP (Fig. 1). Details of the histogram are presented in Fig. 2.

Transitions between a target land cover and the other land cover types can be regarded as the manifestations of cropland change (van Vliet et al., 2015), e.g. agricultural expansion is a proximate cause of deforestation, while urban expansion can be a proximate cause of cropland loss. By borrowing this concept, we develop the landscape

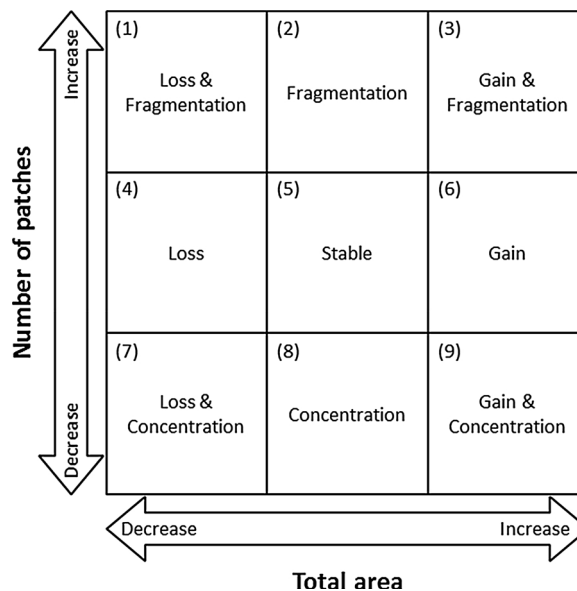


Fig. 1. Characterization of cropland change. A total of nine groups has been identified to represent the different types of cropland change, based on the combination of changes in total area and number of patches.

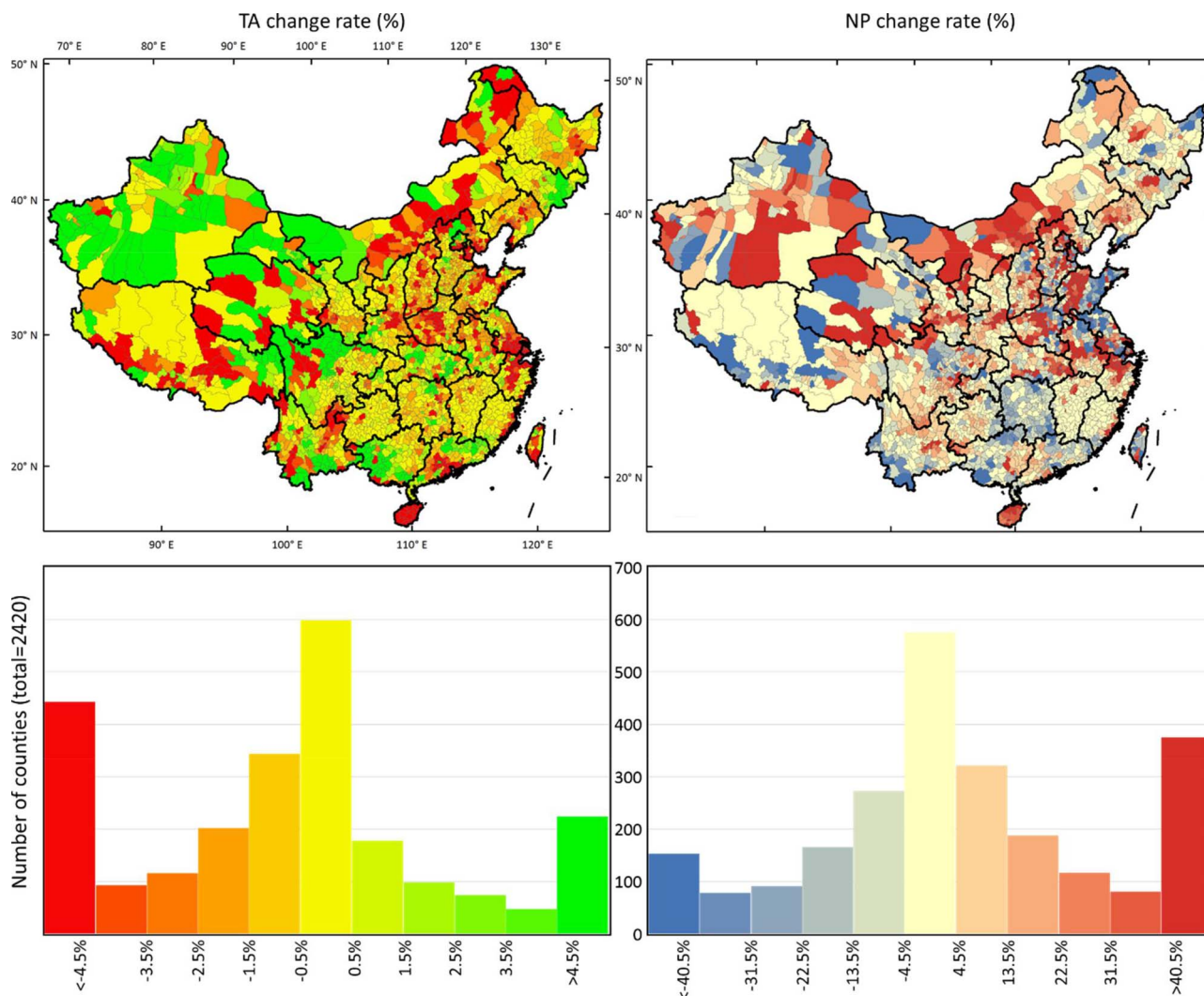


Fig. 2. Characterization of cropland change in China at a county level. The histograms of TA change rate and NP change rate are displayed in lower-left and lower-right, respectively. The spatial distributions of TA change rate and NP change rate are displayed in upper-left and upper-right, respectively. Colors in the maps correspond with the histograms, and intervals are set following the Freedman-Diaconis rule (see Section 2.2).

conversion matrices for cropland at the county level basis, quantifying the gain and loss of cropland area from/to the other land cover types. Specifically, we assess what land cover type is the largest contributor to the observed cropland change. For example, in a county that is characterized by a net cropland loss in combination with cropland fragmentation, we look for the land cover type that makes the largest gross contribution to the observed cropland loss. We further adopt such a gross area conversion as the manifestation of cropland change to the identified characterizations in terms of both TA and NP.

### 3. Results

#### 3.1. Observed cropland change

The distributions of TA changes and NP changes across counties are presented in the lower part of Fig. 2. These figures show that about 25% of the total counties remain stable for either TA or NP, and that the number of counties decrease with increasing amount of change. Fig. 2 also shows that a decrease in TA predominates across counties, while an increase in NP prevails. The locations of TA changes and NP changes are illustrated in the upper part of Fig. 2. It shows that most counties located in Northern and Central China experienced a net loss in cropland, including Inner Mongolia, Hebei, Henan, Shanxi, Shaanxi,

Shandong. Counties with higher NP changes are also located in the North China Plain (Hebei, Henan, Shanxi, Shandong, and the northern part of Anhui and Jiangsu), in addition to the vast territory of Inner Mongolia and Xinjiang. The spatial patterns of TA and NP in the year 2000 and 2010 are displayed in the Supplementary Information (SI).

Following the bin width estimated from the histogram-based approach, nine combinations of cropland change can be found, as presented in Section 2.2. The indicator-combining analysis suggests that the counties with TA loss and NP increase predominate in China, as 703 out of 2420 are characterized accordingly (Fig. 3). This figure further shows that cropland loss is frequently accompanied with fragmentation in China between 2000 and 2010.

Counties with TA loss and NP increase – the largest group across the whole country – are mainly located in the North China Plain, the Lower Yangtze River Basin, as well as Liaoning, Hainan, central Inner Mongolia, north Zhejiang, east Yunnan, west Guangdong. Counties with TA loss and NP decrease – the second largest group observed (313 out of 2420) – are mainly located in the South (Hunan, Yunan, and Guangxi), east Shandong, and north Jiangsu. Counties with no change in TA and NP, measuring 279 counties, are mainly located in the Southeast (Jiangsu and Fujian). Other types of cropland change are distributed more scattered throughout the country (Fig. 3).

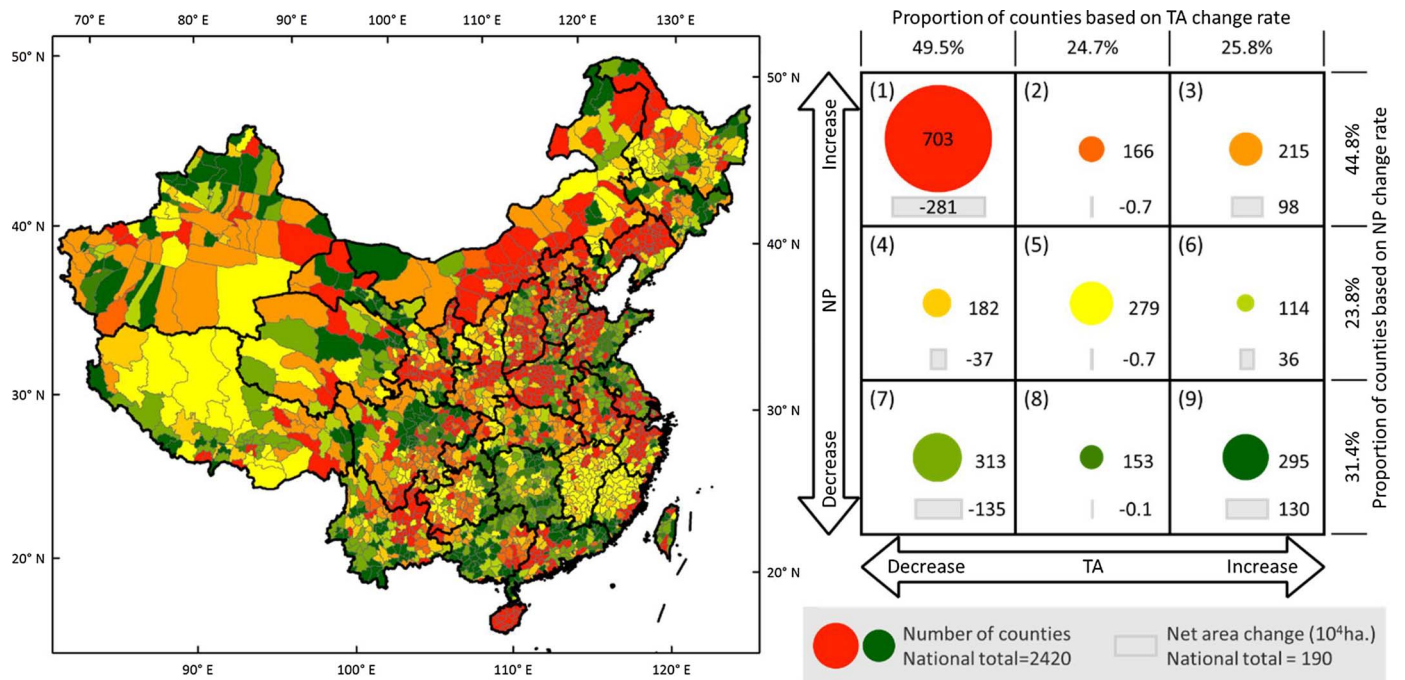


Fig. 3. Characterization of cropland change in China combining TA change rate and NP change rate. The left map presents the spatial distribution at the county-level basis, while the right figure illustrates the legend of the map as well as the statistics of the characterization results.

### 3.2. Manifestations of cropland change

There is much more gross change in cropland than net change, as we found a 10.5 million ha gross decrease and an 8.6 million ha gross increase between 2000 and 2010, yielding a 1.9 million ha net cropland loss. In other words, net change only accounts for 9.9% of the total gross change in cropland. The conversion matrix also indicates that cropland change is mainly related to changes in forest, grassland, water, and artificial land at the national level (Fig. 4). Fig. 5 illustrates the largest contributor of gross cropland change, in which only counties with change in both TA and NP are selected for the illustration (see Fig. 3, the corner groups).

Fig. 5 shows some clear relations between cropland change and its manifestations: Fig. 5(1) shows that cropland fragmentation is mainly associated with artificial land development in the North China Plain, with grassland occupation in part of Inner Mongolia, Liaoning and Yunnan, and with forest occupation in Hainan province. Fig. 5(7) shows that a larger cropland loss to artificial land in parts of the North China

Plain as well as southern China might yield cropland concentration, but the pattern is more scattered. It also shows that cropland loss in the West is mainly associated with increased forest and grassland. The right figures both show that a net increase in cropland is mainly related to a conversion of forest and grassland. The reclamation on grassland would more likely yield an overall cropland fragmentation in the West (Fig. 5(3)). The clearance of forests might also lead to fragmentation in some places (Fig. 5(3)), while it is related to cropland concentration elsewhere, especially in the south (Fig. 5(9)).

## 4. Discussion

### 4.1. Bridging the gap of cropland change studies across disciplines and scales

Different ways of measuring cropland change have been used across the literature. Net area changes of cropland, as well as other land uses, are used most often. Such a simple indicator has been used, for

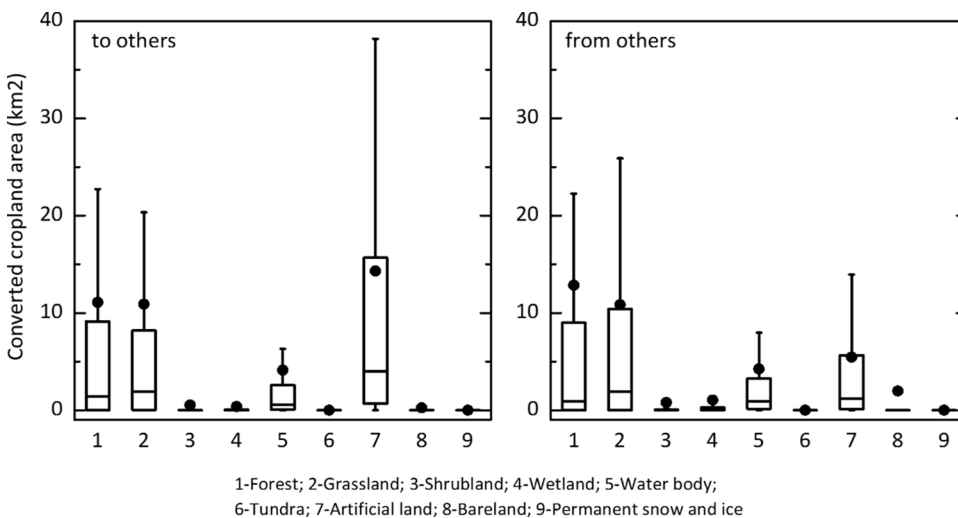


Fig. 4. Landscape conversions representing cropland loss (left) and gain (right) to/from other land cover types. The figure is plotted based on county level values. The boxes indicate the 25%–75% percentile, the whiskers indicate the 5%–95% percentile, the lines within the boxes indicate the median, and the dots indicate the average values of each land cover type. The values out of the 5%–95% percentile scope might not be presented in the figures.

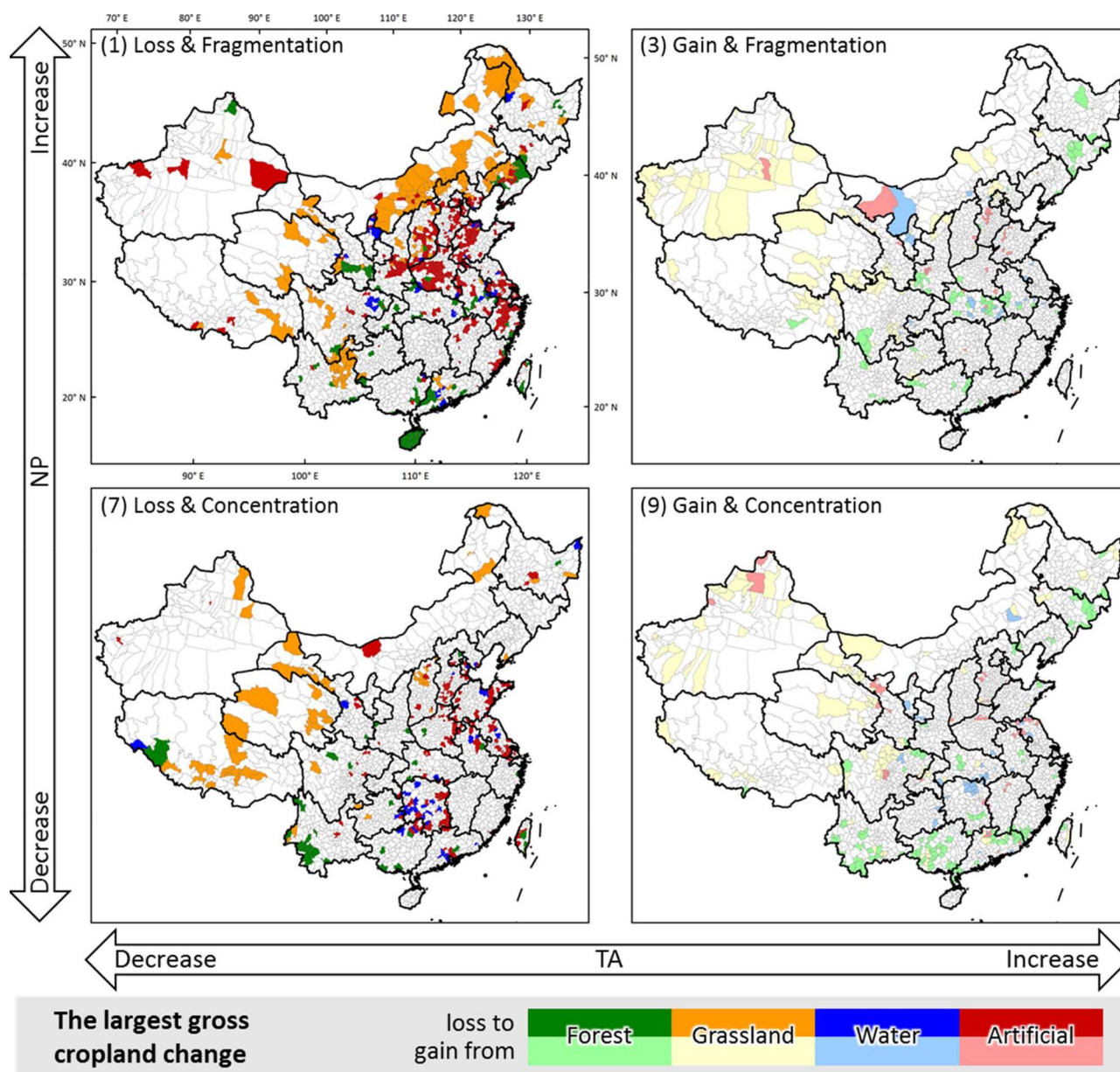


Fig. 5. Manifestations of cropland change, characterized by the largest gross change to the identified characterizations in terms of both total area and number of patches. Different colors indicate different land covers converted from or to cropland. Darker colors indicate gross cropland loss while lighter colors mean gross cropland gain. Only the counties with change in both TA and NP are displayed (see Figs. 1 and 3).

example, in economic models to indicate the resource capacity of agricultural sector (Schmitz et al., 2014), and in earth system models to measure the land use impacts on global climate (Deng et al., 2013). Recent work by Fuchs et al. (2015) and Pongratz et al. (2014) has shown the importance for accounting for gross changes of land use rather than only focusing on net change. However, there are few studies that, across larger spatial scales, assess the spatial structure of cropland. Even the mosaic representation of land systems are typically based on land cover compositions (including the fraction of cropland), rather than the landscape pattern (van Vliet et al., 2017). In our study, we have combined these different indices of change in studying cropland change in China, and we confirmed the hypothesis that more gross changes might only result in a limited net change, but it is associated with a much larger change in landscape pattern.

Cropland fragmentation is context-, and scale-dependent. For example, the physical, social, and operational fragmentation have been conceptualized for different research disciplines, which focused on non-

contiguous land parcels, scattered and downsized ownership, and mismatch between different scale of holdings and recourse accessibilities respectively (King and Burton, 1982; Sabates-Wheeler, 2002). The measurements are different from each other as well. For example, the physical fragmentation is mostly presented in a spatially explicit way based on fine resolution remotely-sensed images (Baldi et al., 2006; Su et al., 2014; Cheng et al., 2015). While socioeconomic data such as census and cadaster are frequently used for describing ownership fragmentation, e.g. using per capital cropland as an indicator (Tan et al., 2006; Deininger et al., 2012). Although the physical, social, and operational fragmentation might be related to each other, there are few studies that combine these aspects together, due to the lack of a human-land integrated observing system (Yu et al., 2017). Complicating factor is the high scale-dependence of fragmentation because “landscape” is not a geographically precise unit of measurement (Meentemeyer and Box, 1987). Therefore, cropland fragmentation can be understood at pixel, plots/households, village, and district levels, which are

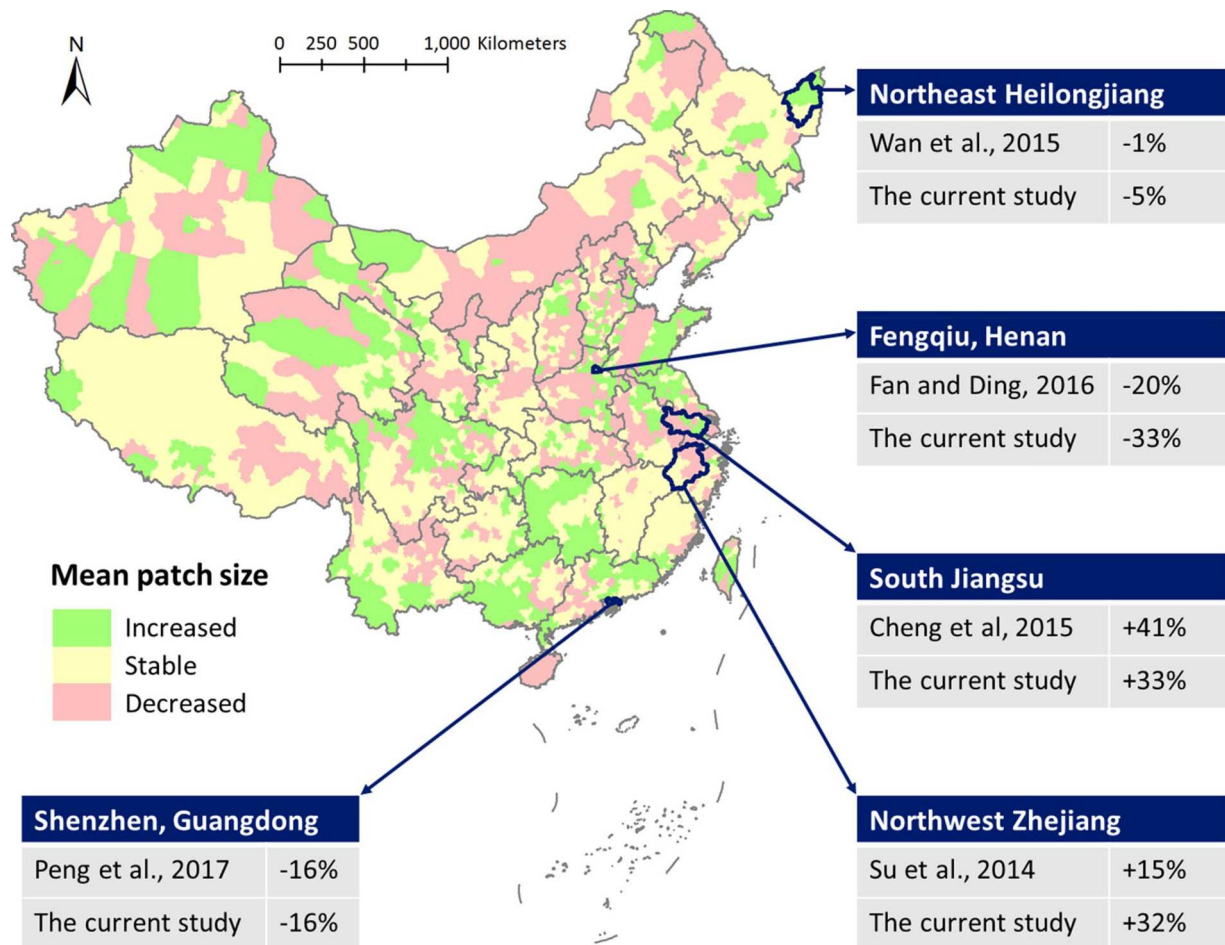


Fig. 6. Comparison of NP change rate with five relevant local scale case studies (highlighted out in tables); and spatial distribution of the classification of mean patch size change at the county-level basis, with thresholds set according to the histogram-based approach (see Section 2.2).

underpinned by different processes and would have different consequences on crop production, biodiversity and biomass (Müller and Munroe, 2008).

Our study bridges the gaps of cropland change studies cross disciplines and scales. First, its purpose fits land system science that is to observe and explain the changes of cropland cover, while an extra landscape indicator is used in addition to the widely-used indicator (i.e. total area) for improving the characterization, and the net area changes are disentangled to larger gross area changes for better manifesting the characterization. Second, unlike the traditional socioeconomic studies, our study explores the physical fragmentation at the land cover level. Therefore, the applied data and the meaning behind are totally different from those ownership fragmentation studies. A comparison using the current results as proxy against other fragmentation studies would thus be interesting. Third, in contrast to existing studies which have preliminarily examined cropland fragmentation at small scales, e.g. Peng et al. (2017b), Fan and Ding (2016), Wan et al. (2015), Cheng et al. (2015) and Su et al. (2014), we provide a national level overview. Fig. 6 shows the comparison of NP change rate with these five relevant case studies. It suggests that the global datasets are fairly consistent with local case studies and thus allow capturing the detailed landscape characteristics, and cross country/region comparisons as well. Moreover, most of the existing studies investigated the landscape indices independently, our study characterizes cropland change in both terms of area and structure. It is believed that integrating landscape characteristics would deepen our understanding of the geographies of agricultural land use change (Wadduwage et al., 2017).

#### 4.2. Implications and limitations

We measure cropland fragmentation as an aspect of land change processes complementary to the well-documented area change, and reveal how changes in land cover and landscape pattern interact with each other. Our results suggest a strong trend of cropland fragmentation associated with a relatively small area loss. These findings are partly supported by the smaller scales studies, e.g. Cheng et al. (2015) and Su et al. (2014). The predominant trend of cropland loss and fragmentation lead to a decreased mean patch size in many counties across China (Fig. 6), and the average county level mean cropland patch size decreased by 28.1%, against to a sharp increase of mean patch size of urban land, see Fang et al. (2016).

We find that the expansion of artificial land is the most significant contributor for both cropland loss and fragmentation (Fig. 5(1)) in the flat and productive North China Plain, indicating the current urbanization process may take place at the cost of cropland, and further fragment the concentrated cropland patches into smaller pieces. This is in correspondence with the existing studies that show that urban land is often taken from primary cropland (Xu et al., 2016), and that the fragmentation due to urbanization might be further accelerated by peri-urbanization (van Vliet et al., 2017), i.e. the landscape interface between town and country where cropland and artificial land are interwoven. On the other hand, the net cropland increase is mainly related to conversion of grassland and forest in the Northeast, Northwest and South. This suggests that the national level cropland “increasing vs. decreasing balance” policy inevitably makes infringements into the more conserved ecosystems, in order to balance the noticeable cropland

loss in the more fertile regions. While it should also be noted that some counties in the West and South China have witnessed cropland loss associated with forest and grassland regrowth, and cropland becomes more concentrated overall (Fig. 5(7)). This suggests that the ecological restoration programs (known as “Grain for Green”) might have successfully converted the marginal cropland, thus decreased the number of cropland patches (Wang et al., 2017). However, it should be noted that while our analysis established clear relations, it does not reveal the causal mechanisms underlying these relations. Such analysis would require an assessment of biophysical and socioeconomic conditions in the processes of cropland fragmentation cross scales, e.g. in those hotspot areas.

Our study adopts NP for measuring the changes in landscape pattern. A large number of other indices have been developed to measure landscape fragmentation, including patch density, cohesion index, splitting index, effective mesh size, normalized landscape shape index, perimeter area ratio distribution and aggregation index, etc., in addition to TA and NP, see Jaeger (2000), Li and Wu (2004), and Uuemaa et al. (2009). However, comparisons show that different landscape metrics are often strongly correlated (Riitters et al., 1995; Peng et al., 2010; Plexida et al., 2014), justifying a selection rather than an inclusion of all metrics for the assessment of cropland changes. Hence, while NP might not cover all aspects of fragmentation, we believe it is a meaningful indicator for such a large-scale analysis, especially when it is used along with TA: one controls the total amount, the other reflects the discreteness. Adding additional metrics would most likely blur the overall image rather than add clarity.

#### 4.3. Data uncertainties

The GlobalLand30 dataset in the year 2000 and 2010 has been used for analyzing the cropland change in China, and the land conversion matrixes have been developed for quantifying the cropland gain and loss from/to other land cover types. This shows a 1.89 million ha cropland net loss between 2000 and 2010, equal to 0.9% of the total cropland in China. The numbers are slightly higher than Liu et al. (2014a)’s work. Land cover in the 2000 and 2010 as included in the GlobalLand30 have been intensively validated during the dataset production (Chen et al., 2015; Han et al., 2015). Those measurements – mainly based on confusion matrix, including overall accuracy, kappa coefficient, users’ accuracy, producers’ accuracy – suggest that the data accuracy in both 2000 and 2010 are fairly high. However, these accuracy measures are not necessarily valid for analyzing changes between the two-stage datasets, because any small positioning errors in adjacent pixels between the two year could lead to an erroneous change signal, even though the data at each time stage are assessed with a high accuracy. We refer this as “swap effect” (Pontius et al., 2004), which may result in a pseudo gross change, even while there is no net change and real change. Therefore, we developed a systematic procedure to quantify such effect. We randomly select 6000 windows by 2\*2 pixels within the whole country, for each window, we define a window with swap effect if it meets both of the following conditions: (i) the share of each land cover are exactly the same at the year 2000 and 2010, but (ii) the spatial locations of the specific land cover pixels are swapped. The result show that only 3 out of 6000 pixels are having such swap effect (see details in the SI). Therefore, we believe the data quality is good enough to sustain the current analysis and no extra uncertainties need to be quantified.

Surprisingly, we find that about 1.46 million ha artificial land has been converted to cropland at the national level (Fig. 4). This challenges the common understanding that the conversion from artificial land to cropland is less possible or merely the result of classification swaps. The analyses of error, including the validations at each time stage and the quantification of swap effect between the two maps, could not invalidate these observed conversions. Although there may be other uncertainties, there is a strong indication that a considerable area of

artificial land is converted to cropland. Since the early 2000s, the Chinese government has implemented a national land consolidation project to make sure the cropland “increasing vs. decreasing balance” policy, including the reclamation of wasted mine and hollowed villages for agricultural production (Huang et al., 2011; Long et al., 2012). According to the “National Land Consolidation Plan (2011–2015)”, the land consolidation project had brought about 2.76 million ha cropland increase at the national level since from year 2001 to 2010, and artificial land is one of the important sources. When comparing these numbers, we noticed that the 1.46 million ha (as shown by GlobalLand30) is limited to the gross cropland increase from artificial land, while the increase of 2.76 million ha cropland is unspecified. It means the evidence from GlobalLand30 could partly reflect the outcomes of the land consolidation project. However, it also reveals that the detailed documentations of the effects of land consolidation projects – in terms of location, duration, as well as the processes, drivers and consequences of consolidation – are scattered and limited (Li et al., 2014; Liu et al., 2016; Tang et al., 2017). Given our study provides the national level overview, it may help to identify hot-spot areas for more detailed analysis of this issue.

## 5. Conclusion

Cropland is vital for human society, while various case studies have been conducted on cropland change, most of which are aimed at the area change of cropland without focusing on spatial patterns of cropland distribution. Our study reveals that many counties in China have experienced little cropland loss, but were associated with large fragmentation in the first decade of the 21st century. It confirms the hypothesis that the small net area changes are commonly associated with larger gross area changes as well as greater changes in landscape pattern. Our study also shows that cropland loss and increased fragmentation is mainly found in areas with urban development, while cropland gain and decreased fragmentation is mainly related to a conversion of forests. For example, cropland in the North China Plain – an important breadbasket in China – is largely fragmented due to the conversions between cropland and artificial land. This could be the result of policy interventions: the recent cropland conservation policies worked out well for protecting the total cropland area in China, but resulted in an underestimated cropland fragmentation. In other parts of China, the afforestation programs may have successfully returned the marginal cropland patches and thus enabled a cropland concentration. However, it also suggests that the land consolidation project did not contribute much to cropland concentration at the land cover level. The comparison between our study with other relevant local scale case studies suggests the alternatives of using GlobalLand30 for observing detailed landscape changes across scales, indicating further investigations on the causes and consequences of cropland fragmentation (e.g. on agricultural production) are possible based on the application of GlobalLand30.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.jag.2017.11.002>.

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