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REPORT

# Characterizing Long-Term Land Use/Cover Change in the United States from 1850 to 2000 Using a Nonlinear Bi-analytical Model

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**Abstract** We relate the historical (1850–2000) spatial and temporal changes in cropland cover in the conterminous United States to several socio-economic and biophysical determinants using an eco-region based spatial framework. Results show population density as a major determinant during the nineteenth century, and biophysical suitability as the major determinant during the twentieth century. We further examine the role of technological innovations, socio-economic and socio-ecological feedbacks that have either sustained or altered the cropland trajectories in different eco-regions. The cropland trajectories for each of the 84 level-III eco-regions were analyzed using a nonlinear bi-analytical model. In the Eastern United States, low biophysically suitable eco-regions, e.g., New England, have shown continual decline in the cropland after reaching peak levels. The cropland trajectories in high biophysically suitable regions, e.g., Corn Belt, have stabilized after reaching peak levels. In the Western United States, low-intensity crop cover (<10 %) is sustained with irrigation support. A slower rate of land conversion was found in the industrial period. Significant effect of Conservation Reserve Program on planted crop area is found in last two decades (1990–2010).

**Keywords** Land cover change · Cropland change · Spatial determinants · United States

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## INTRODUCTION

Land use/cover change is an anthropogenic-driven phenomenon that has occurred globally in concert with population growth (Ramankutty et al. 2002a; Foley et al. 2005; Pongratz et al. 2008). Land use/cover change has several important implications including impacts on global and regional climate, hydrologic cycle, biogeochemistry, fragmentation, and/or loss of habitats (Gordon et al. 2005; Gruber and Galloway 2008; Pielke Sr. et al. 2011; Pijanowski and Robinson 2011). While a number of studies have documented the magnitude and direction of land cover change, the investigation of underlying governing mechanisms of land cover change at national scale is limited. For example, how socio-economic and biophysical determinants contributed toward land cover change over the twentieth century, requires further investigation. Land use/cover change and cropland change is used interchangeably in this study, because cropland change is the most extensive form of global land cover change (Pongratz et al. 2008; Pielke Sr. et al. 2011).

Biophysical determinants such as topography, soil, and climatic conditions, e.g., temperature and precipitation have played an important role for global cropland distribution (Fisher et al. 2002). The population increase is the main driver for cropland expansion in the last millennium (Pongratz et al. 2008). Apart from population, other socio-economic determinants include technological advances, government policy, transport network, distance from the city/market/employment center, and social and cultural values (Verburg et al. 2004; Sohl et al. 2007). Socio-ecologic feedbacks are the actions taken by the society/government as a result of degrading environmental concerns, e.g., soil erosion and water quality problems (Lambin and Meyfroidt 2010).

Studies related to global historical distribution of cropland from 1700 to present are based on coarse-resolution crop inventory data at national/sub-national scale (Ramankutty and Foley 1999), and population density as the primary determinant for cropland distribution [Historical Database for the Global Environment (HYDE3), Goldewijk and Van Drecht 2006]. The HYDE3 study also found population density was an unsuitable proxy for cropland spatial distribution in the twentieth century. At regional scale, the USGS Land Cover Trends project provides detailed geographic characteristics of land cover change over the last 4 decades based on high-resolution satellite images (Loveland et al. 2002; Drummond and Loveland 2010). However, these data are limited in their temporal coverage to investigate long-term trends in land cover change.

Mustard et al. (2004) found broad commonalities in the land cover change trajectory and impacts. Mather and Needle (1998) proposed the theory of increasing agricultural adjustment to land quality. Lambin and Meyfroidt (2010) suggested two theoretical pathways for land use transition: (i) negative socio-ecological feedback that arises due to endogenous factors, such as severe decline in natural ecosystem services and (ii) socio-economic dynamics that arise due to exogenous factors, such as technological innovations and economic modernization. By analyzing the recent forest transition in Vietnam, Lambin and Meyfroidt (2010) found that the two pathways are not independent. Socio-ecological feedbacks explain the slowing down of deforestation better, but the sustainable reforestation activity is maintained by socio-economic dynamics.

Land use change is a multi-disciplinary science. Land use change has been studied at various spatial scales (e.g., patch, county, regional, and global scales), and at a variety of temporal scales (e.g., few decades to millennium) by geographers, ecologists, socio-economic scientists, and earth-system scientists (Williams 1989; Turner et al. 1990; Ramankutty and Foley 1999; Lambin et al. 2001; Medley et al. 2003; Wu 2006; Pongratz et al. 2008; Ray and Pijanowski 2010; Pijanowski and Robinson 2011). Factors affecting land cover change can vary depending upon the scales and scope of the study. For example, Medley et al. (2003) found land ownership as an important driver for the land use change in a county level study in the United States. Ray and Pijanowski (2010) modeled land use change in a regional watershed in Michigan finding that one location could pass through several land use classes (e.g., forest → agriculture → shrubland → forest → urban) over the span of a century. By synthesizing regional land cover change case studies in recent decades, Lambin et al. (2001) emphasized the role of institution/governance, and people's response to the economic opportunities as the major driver of land cover change. This study focuses on integrating land cover change and its determinants across a sub-continental scale.

Land cover change has occurred over a large geographic area of the conterminous United States (8.08 million km$^2$, Fig. 1a). The United States topography and climate can be categorized by as many as 84 level-III eco-regions (Omernik 1987). An eco-region denotes a relatively homogeneous area in terms of soil, topography, climate, vegetation, and hydrology. Level-III eco-regions are third on the hierarchical subdivision levels following Level-I, which divides North America into 15 ecological regions, and Level-II, which divides North America into 50 classes. Level-III eco-regions have been used as a spatial unit to study land cover change characteristics in USGS land cover trends project (Loveland et al. 2002; Drummond and Loveland 2010).

Since the arrival of Europeans on the eastern seaboard in early seventeenth century, the United States has undergone major land cover change (Williams 1989; Whitney 1994). The expansion of settlement toward the West during the nineteenth and twentieth centuries (Fig. 1b), government policy intervention, e.g., state drainage law (Whitney 1994), and the advent of mechanized agriculture in post Word War II period have further shaped the agricultural landscape across the sub-continent. Detailed agricultural data (county level) are available since 1850 (Waisanen and Bliss 2002). The overarching question addressed in this study is what are the socio-economic and biophysical determinants of long-term agricultural change at the sub-continental scale, and how have the determinants changed through time? The specific objectives are (i) to quantify the contribution of biophysical and socio-economic determinants for cropland distribution in the conterminous United States from 1850 to 2000, (ii) to study the dynamics of cropland trajectories, e.g., the rate of land cover change in 84 eco-regions using a nonlinear bi-analytical model taken from traditional mathematics.

## MATERIALS AND METHODS

### Determinants of Land Cover Change

The biophysical and socio-economic determinants are selected based on a literature review, availability of spatial data, and spatial and temporal scale of the study (Verburg et al. 2004; Sohl et al. 2007). The land cover change determinants such as technology and government policy are considered as non-spatial data, i.e., these data do not vary among different eco-regions. For example, technological innovations such as fertilizer application, and mechanization of agriculture were equally available for all areas in the United States. The role of non-spatial data on

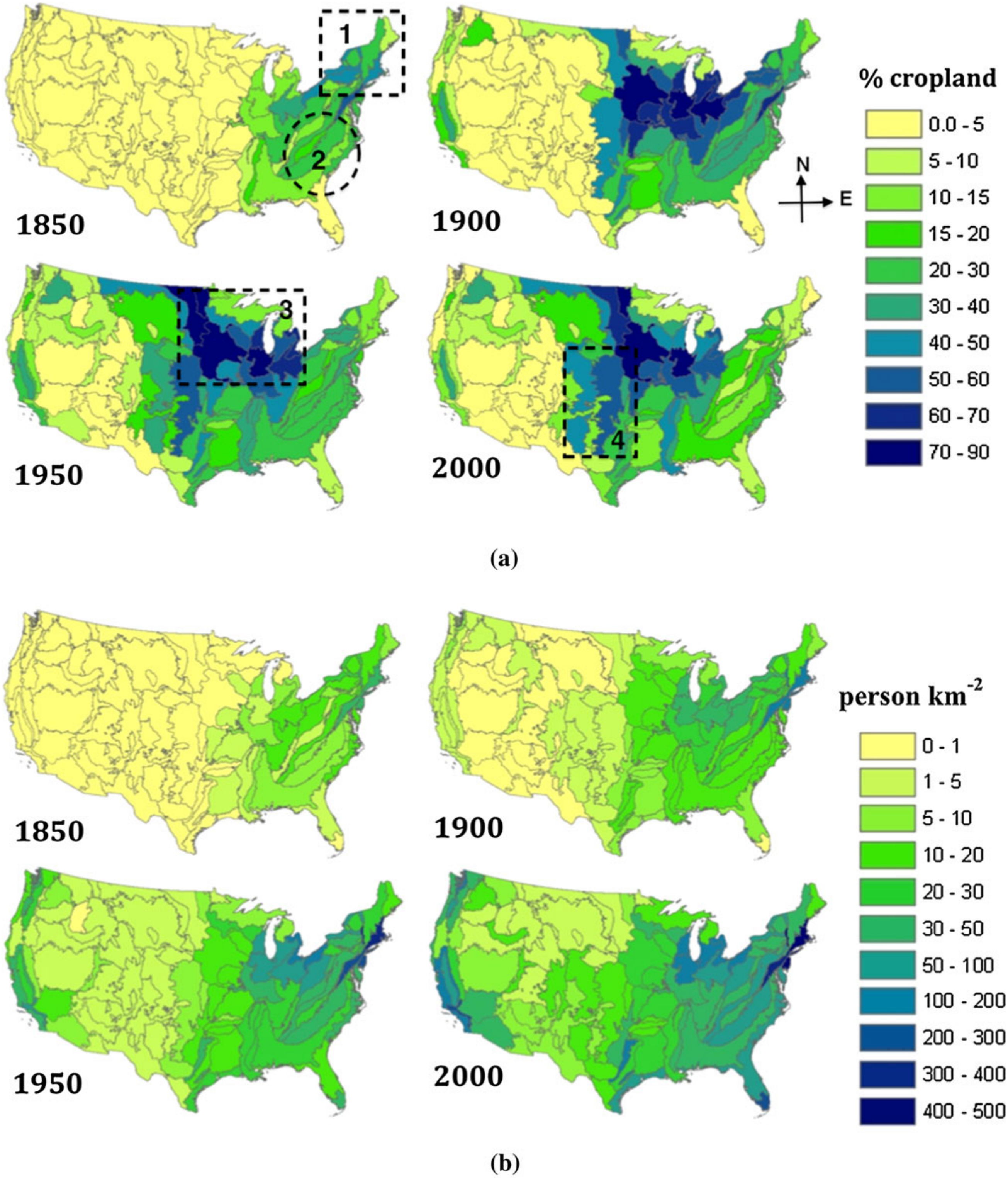


**Fig. 1** **a** Land cover change (cropland) in the United States. Cropland distribution in level-III eco-regions is shown for four time slices: 1850, 1900, 1950, and 2000. Decline in cropland after 1900 is evident in New England (region 1) and Southeastern United States (region 2); whereas cropland has expanded in Midwestern United States (region 3), High Plains (region 4) during 1900 and 1950, and remained almost the same during 2000. Low-intensity agriculture (<10 %) is also evident in the western United States. **b** The settlement expansion (population density) in the United States. The average population density (person $km^{-2}$) in level-III eco-regions are shown for four time slices: 1850, 1900, 1950, and 2000. During the nineteenth century, the population was largely concentrated in the eastern United States; the population expanded toward the west during the twentieth century. Eastern United States remains a densely populated compared to western United States even at present time

**Table 1** List of spatial dataset used in the study

| Sl. no. | Dataset | Source | Original resolution | Re-gridding method | Final resolution |
|---|---|---|---|---|---|
| 1 | Population density (PD)[a] | MPC[b] | County (~42 km)[h] | Area weighted average | 0.5° (~50 km) |
| 2 | Cropland % (CP)[a] | WB2002[c] | County (~42 km) | Area weighted average | 0.5° (~50 km) |
| 3 | Elevation (ELEV) | HYDRO1K[d] | 1 km | Local area averaging | 0.5° (~50 km) |
| 4 | Slope (SL) | HYDRO1K | 1 km | Local area averaging | 0.5° (~50 km) |
| 5 | Topographic index (TI) | HYDRO1K | 1 km | Local area averaging | 0.5° (~50 km) |
| 6 | Dryness index (DI) | PRISM[e] | 4 km | Local area averaging | 0.5° (~50 km) |
| 7 | Annual temperature (AT) | PRISM | 4 km | Local area averaging | 0.5° (~50 km) |
| 8 | Crop suitability index (SUIT) | RM2002[f] | 0.5° (~50 km) | Not applicable | 0.5° (~50 km) |
| 9 | % Water and Wetland (WP) | NLCD2001[g] | 30 m | Local area sum | 0.5° (~50 km) |
| 10 | % Urban area (UP) | NLCD2001 | 30 m | Local area sum | 0.5° (~50 km) |

[a] PD and CP estimates are from 1850 to 2000 per decade

[b] Minnesota Population Center (2011)

[c] Waisanen and Bliss (2002)

[d] USGS topographic datasets derived from 30 arc-second (~1 km) digital elevation model

[e] Parameter-elevation regressions on independent slopes model

[f] Ramankutty et al. (2002b)

[g] National Land Cover Dataset 2001

[h] County resolution (~42 km) is based on average county area (1766 $km^2$) of the conterminous United States

overall cropland trajectory is discussed in "Role of technology, socio-economic, and socio-ecological feedbacks" section based on available literature and new data available from Conservation Reserve Program (CRP).

Spatial data used in the study are listed in Table 1. All data are re-gridded to a common resolution of 0.5° × 0.5° (approximately $50 \times 50 = 2500$ $km^2$), which is roughly equivalent to average area of counties in the United States (~1800 $km^2$). The population and cropland data are based upon United States census reports (Waisanen and Bliss 2002; Minnesota Population Center 2011). Dryness index (DI) is an indicator of water availability; DI $< 1$ indicates humid region, e.g., eastern United States, and DI $> 1$ indicates semi-dry to dry region, e.g., western United States (Budyko 1958). Annual temperature and precipitation data are based on 4-km resolution PRISM climate data (1950–2000 average; Daly et al. 1998). The biophysical suitability index (SUIT) is a function of growing degree days, moisture index, soil carbon content, and pH (Ramankutty et al. 2002b). Half-degree resolution data were clipped to eco-region boundaries, and eco-region average values of all variables were obtained using local area averaging (Fig. 2). The local area averaging method accounts for fractional contributions of the input high-resolution grid points to the scope of each eco-region/low-resolution grid.

A multiple linear regression model with a stepwise selection method (entry and stay significance level = 0.10) was used to determine major determinants explaining the variance in the spatial distribution of cropland for each decade from 1850 to 2000. To obtain a meaningful result, eco-regions having an average population density of greater than 1 person $km^{-2}$ were included in the regression analysis. A power transformation (Box and Cox transformation) was used to bring non-normally distributed variables into a normal distribution. Only one in a pair of variables (pair 1: population density and urbanization and pair 2: topographic index and slope) having correlation coefficient $> 0.7$ was included in the regression analysis. See Sect. S.1 in Electronic Supplementary Material for detail.

## Nonlinear Bi-analytical Model for Land Cover Change

Land cover change has occurred at different time periods across 84 eco-regions. For example, agricultural expansion has occurred very recently (last 3–4 decades) in lower Mississippi River Valley, and Florida region, whereas in New England region the agricultural expansion had occurred in the early nineteenth century (Fig. 3a). A visual comparison of 84 land cover change plots together is a tedious job. Furthermore, it does not provide an objective measure (quantitative) to study similarity and differences in land cover change patterns. Hence, we have developed a mathematical functional form based on gamma and beta distribution function to describe cropland change, which we termed as a nonlinear bi-analytical model for land cover

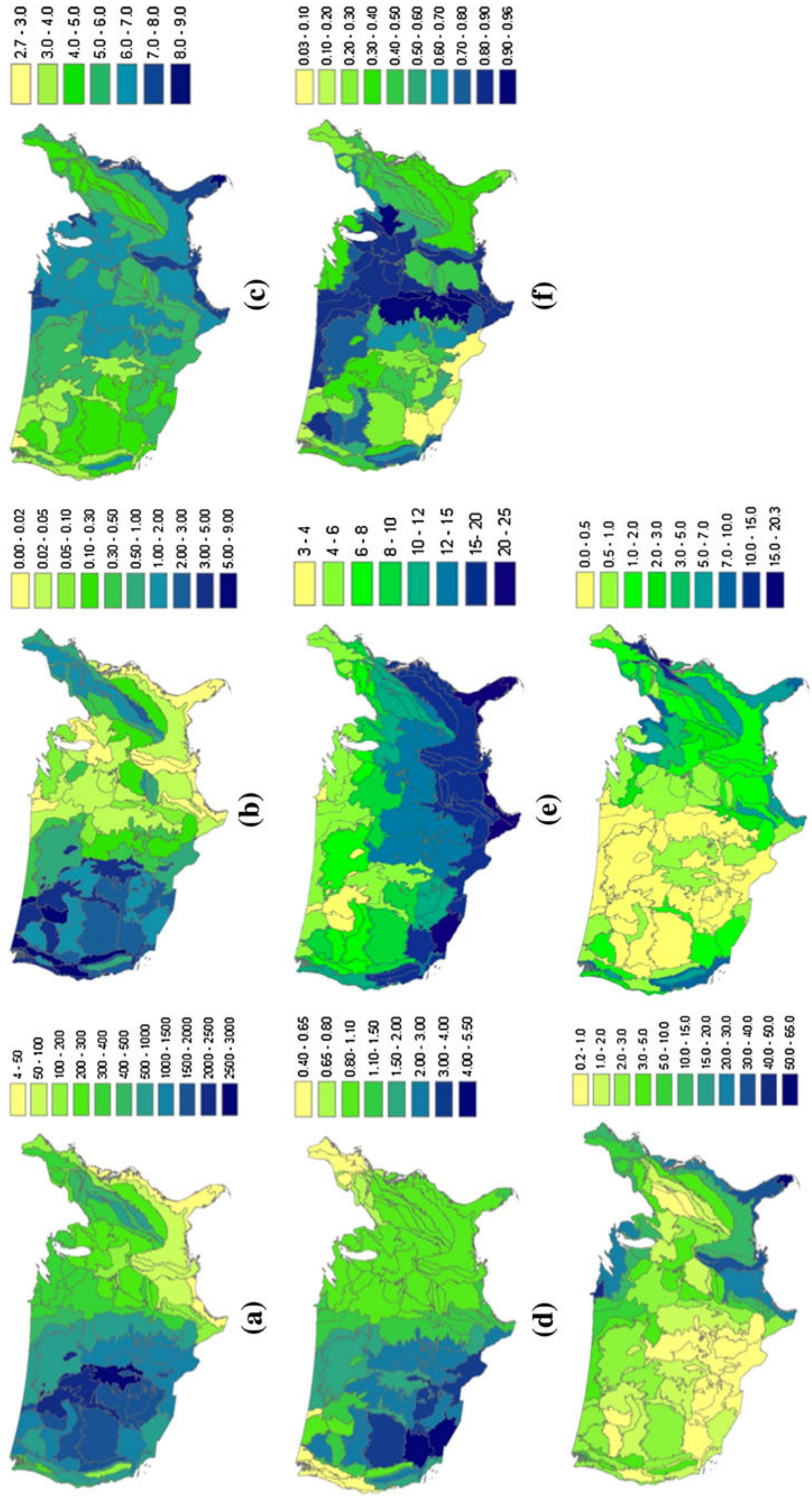


**Fig. 2** Spatial variability in biophysical characteristics in the United States. Level-III eco-region average values are shown for: **a** elevation (m). **b** Slope (%). **c** Topographic index. **d** DI. **e** Annual average temperature (°C). **f** Biophysical suitability index for crop. **g** Water and wetland percentage. **h** Increase in % urban cover (1900–2000)

change. Two advantages of developing the bi-analytical model are (1) cropland trajectories across 84 eco-regions can be compared in terms of model parameters, (2) as there is time lag in land cover change across different eco-regions, the bi-analytical model from an old eco-region, where land cover change has occurred in the past, may be applied or can provide some guidance for a new eco-region, which have similar biophysical characteristics but land cover change is taking place recently (Fig. 3a; the second advantage is not investigated in this study).

In the bi-analytical model, gamma and beta probability density functions (Eq. 1) is fitted to the normalized cropland (%) (Eq. 2) for each eco-region (subscript $i$) as such:

$$F(x) = \Gamma(x) + \beta(x) \tag{1}$$

$$\mathrm{NCP}_{ix} = \frac{\mathrm{CP}_{i,x}}{\mathrm{CP}_{i,\max}} * 100, \tag{2}$$

where $\mathrm{NCP}_{i,x}$ is the normalized cropland (%) for decade $x$ (1 to 16 for 1850 to 2000, respectively), $\mathrm{CP}_{i,x}$ is the cropland (%) for decade $x$, and $\mathrm{CP}_{i,\max}$ is the maximum cropland (%) in the eco-region $i$. As biophysical characteristics are different across eco-regions (Fig. 2), $\mathrm{CP}_{i,\max}$ can be seen as the maximum potential of the eco-region (Fig. 3b; Fig. S.2 in Electronic Supplementary Material). $\Gamma(x)$ and $\beta(x)$ are gamma and beta probability density functions (Eqs. 3, 4). First, the gamma function is fitted to NCP time series for each eco-region, considering NCP as frequency and $x$ as bin value, and then a beta function is fitted to absolute value of residuals ($|\mathrm{NCP}(x) - \Gamma(x)|$).

$$\Gamma(x) = \frac{hv_1}{\Gamma\alpha \cdot \delta}\left(\frac{x-\theta}{\delta}\right) \cdot \exp\left(-\left(\frac{x-\theta}{\delta}\right)\right) \quad \text{for } x > \theta \tag{3}$$

$$\beta(x) = hv_2 \frac{(x-\theta)^{\lambda-1}(\sigma+\theta-x)^{\omega-1}}{\left(\frac{\Gamma\lambda\cdot\sqrt{\omega}}{\Gamma\lambda+\omega}\right)\cdot\sigma^{(\lambda+\omega-1)}} \quad \text{for} \quad \theta < x < \theta + \sigma \tag{4}$$

$$\Gamma z = \int_0^\infty e^{-u} \cdot u^{z-1} \mathrm{d}u, \tag{5}$$

where $\theta$ (=0) is a threshold parameter, $h$ (=1) is the width of histogram interval, $v$ is the vertical scaling factor ($v_1$ is the sum of NCP, $v_2$ is the sum of absolute value of residual ($|\mathrm{NCP}(x) - \Gamma(x)|$)), $\sigma$ (=17) is a scale parameter in beta function, and it is kept constant for all eco-regions. The bi-analytical model parameters ($\alpha$, $\delta$, $\lambda$, and $\omega$) were optimized for minimum sum of square residual ($[\mathrm{NCP}(x) - F(x)]^2$). Goodness of fit was determined using Nash–Sutcliffe efficiency coefficient (NSE; Nash and Sutcliff 1970).

$$\mathrm{NSE}_i = 1 - \frac{\sum_{x=1}^{16}\left(\mathrm{NCP}_i(x) - [\Gamma_i(x) + \beta_i(x)]\right)^2}{\sum_{x=1}^{16}\left(\mathrm{NCP}_i(x) - \overline{\mathrm{NCP}_i}\right)^2}. \tag{6}$$

## RESULTS

Population density increased from 2.9 person km$^{-2}$ in 1850 to 34.4 person km$^{-2}$ in 2000. The cropland area increased from 6 % in 1850 to its peak of 28 % in 1940, and then declined steadily to reach a value of 22 % in 2000 (Fig. 4). The urban area tripled from 1.1 % in 1850 to 3.4 % in 2000. The urban area is based on an urban model for which population density is found to be an adequate determinant ($R^2$: 0.77; see Sect. S.3 in Electronic Supplementary Material).

### Role of Population and Biophysical Determinants

Figure 4 shows the relative contributions of the biophysical determinants and population density for the cropland spatial distributions from 1850 to 2000. Population density was the major determinant of cropland spatial distribution during the nineteenth century, but its contribution has decreased during the last decades of the nineteenth century and early half of the twentieth century. In recent decades (1970–2000), the population density does not explain any variance in cropland spatial distribution. The biophysical suitability has become the major determinant of cropland spatial distribution since 1920; its contribution has increased from 21 % in 1900 to 62 % in 2000. The transition from population density to biophysical suitability as the major determinant occurred during 1890–1920, which coincides with peak development of the rail road network in the United States (Borchert 1967). All other determinants explained less than 10 % of the variance individually.

### Cropland Trajectory and Effect of Biophysical Suitability

The nonlinear bi-analytical model (Eq. 2) adequately describes the cropland trajectories (NCP time series) for all eco-regions (average NSE 0.94; standard deviation of NSE 0.06; NSE 1 indicates a perfect model). The cropland trajectories for selected eco-regions are shown in Fig. 5a–e. For the gamma function, the scale parameter ($\delta$) is correlated with the time to peak of cropland (%) and the shape parameter ($\alpha$) represents the rate of land conversion (Fig. 6). A higher $\alpha$ indicates a slower rate of land conversion (Eq. 3). The $\alpha$ value has generally increased from 1850 to 1950, afterward (1950–2000) it has stabilized (Fig. 6b), indicating the rate of land conversion is slower during twentieth century compared to nineteenth century.

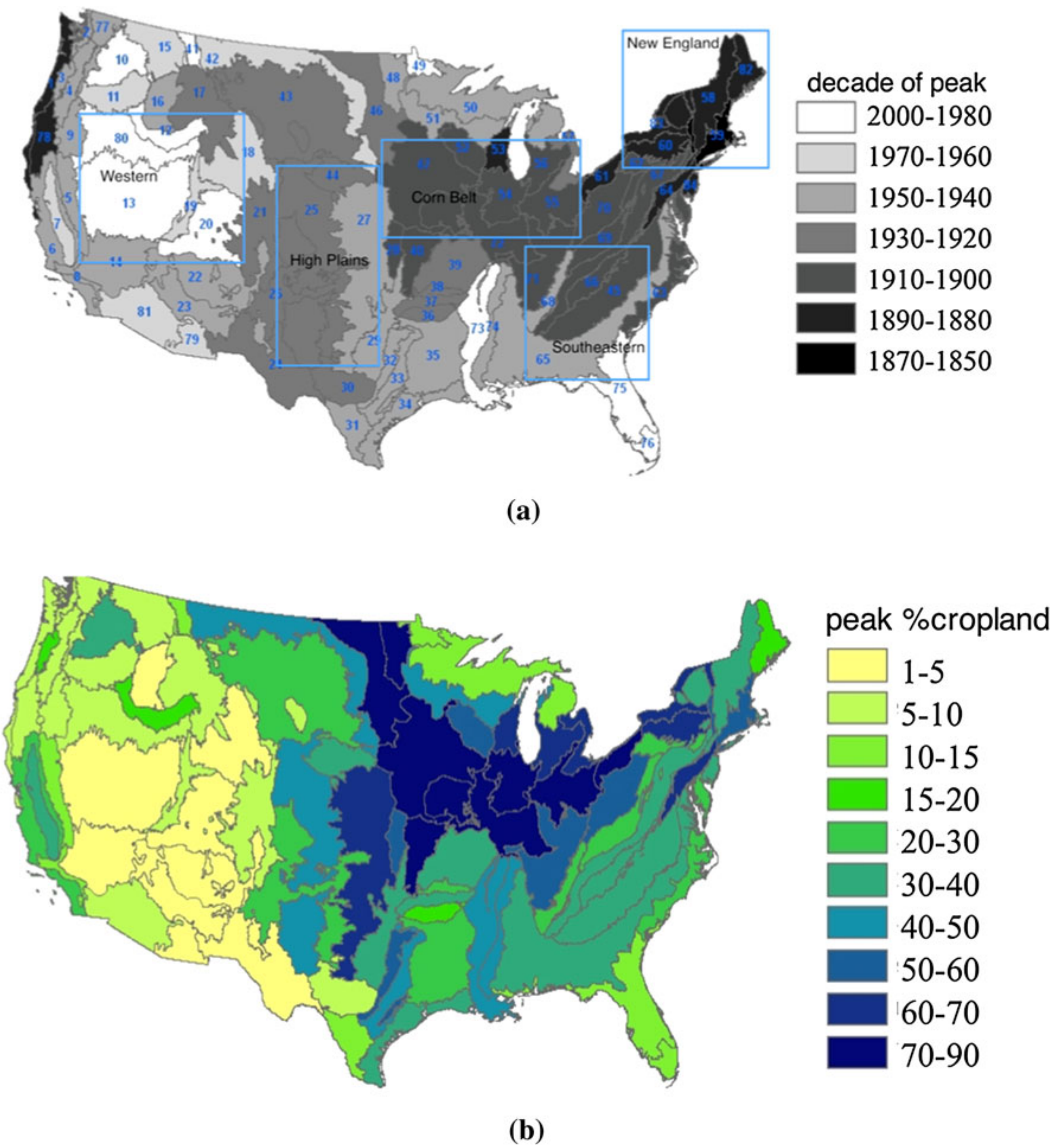


**Fig. 3** **a** Peak cropland (%) decade for level-III eco-regions, an indicator of old versus new eco-regions with respect to cropland expansion. Level-III eco-region numbers are also shown. **b** Peak cropland (%) in each level-III eco-regions for decades 1850–2000, an indicator of maximum cropland potential for each eco-region

The slower rate of land conversion during twentieth century could be due to: (1) technological advances (higher production with lesser cropland; "Role of technology, socio-economic, and socio-ecological feedbacks" section), (2) less land (suitable for cropland) are available for conversion (Eickhout et al. 2006).

The beta function accounts for the departure of cropland trajectory from a purely natural/ecological system, i.e., gamma function (undisturbed land → initial settlement → agricultural expansion → peak cropland → declining cropland). A fnumber of factors, including both endogenous, e.g., biophysical suitability and exogenous, e.g., policy interventions, industrialization, and other technological advances have contributed to the departure. If beta function parameters $(\lambda/\omega) < 1$, the beta accounts for the cropland departure from the gamma function in the frontal half (expansion phase; Fig. 5a, b). If beta function parameters $(\lambda/\omega) > 1$, the beta accounts for the cropland departure from the gamma function in the distal half (stabilization/declining phase; e.g., Fig. 5c–e). The area ratio of beta to gamma functions from 1940 to 2000 [$\mathrm{Ar}\beta 2\Gamma_{(1940\text{–}2000)}$] quantifies the influence of beta function over the falling

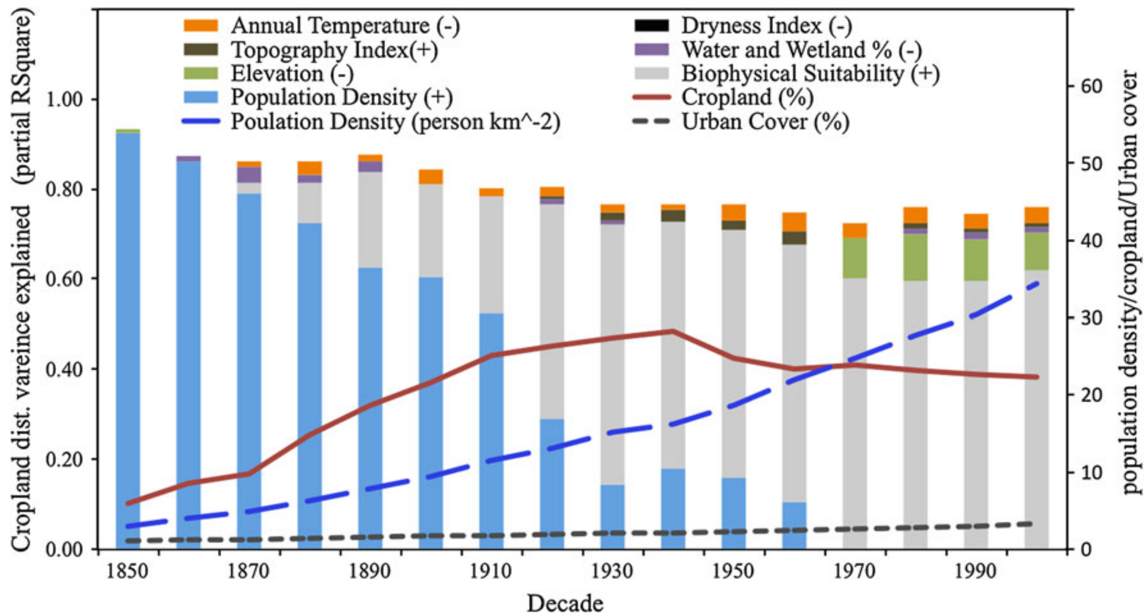


**Fig. 4** Contribution of biophysical and socio-economic (population density) determinants in explaining variance in cropland spatial distribution from 1850 to 2000; expressed in terms of partial $R^2$ values obtained from multiple linear regression ("Determinants of land cover change" section). Conterminous United States average time series of cropland (%), population density, and urban cover (%) are also shown. +/− sign in parenthesis for each variable refer to sign of regression coefficient, found same for all decades, i.e., a negative sign for elevation indicates that the cropland (%) decreases with increasing elevation

limb of gamma function during the latter half of the twentieth century.

The major crop eco-regions ($CP_{max} \geq 30$ %), 40 in all, cover 49 % of the conterminous United States area, and are mostly located in the eastern and central part of the United States with few exceptions in the western United States such as the California Central Valley, and the Columbia Plateau (Fig. 3b). All cropland trajectories can be placed under two broad categories: (1) cropland has continually declined after reaching a peak, such as cropland trajectories in the New England region, and the Southeastern United States (Fig. 5a, b) and (2) cropland has stabilized after reaching its peak, although at slightly smaller level, such as cropland trajectories in the Corn Belt, and High and Great Plains region (Fig. 5c, d).

Of the 40 major crop eco-regions, 28 have SUIT $\geq 0.50$ (Group A), and remaining 12 have SUIT $< 0.50$ (Group B). In the high suitable region (Group A), 26 out of 28 (93 %) eco-regions exhibit stable cropland trajectory (average $\lambda/\omega$: 5.4, average $Ar\beta2\Gamma_{(1940–2000)}$: 0.35); and in low suitable region Group B, 9 out of 12 (75 %) eco-regions show declining cropland trajectory (average $\lambda/\omega$: 0.31, average $ArB2G_{(1940–2000)}$: 0.05). The agriculture is likely to be sustained in the eco-regions that have higher biophysical suitability (SUIT $\geq 0.5$). In the eco-regions, where the agriculture was developed in the less biophysical suitable land (SUIT $< 0.5$) during the initial settlement stages, a continual decline in the cropland is evident.

Twenty-three eco-regions have $CP_{max} < 10$ % (area average $CP_{max}$: 5 %) and all these eco-regions exhibit stable cropland trajectories (average $\lambda/\omega$: 7.0, and average $ArB2G_{(1940–2000)}$: 0.28; Fig. 5e). These eco-regions are located in the Western United States and covers 30 % of the conterminous United States area, and they are not biophysically suitable for agriculture (average SUIT: 0.33; Figs. 2f, 3b). The low-intensity crop activity ($CP_{max} < 10$ %) has occurred in low biophysical suitability region. The remaining 20 eco-regions cover 20.4 % of the conterminous United States area, and have area average SUIT index: 0.54 with 20 % $< CP_{max} <$ 10 %; majority of them (17 out of 20) show stable cropland trajectory. Model parameters for all eco-regions are given in Sect. S.4 of Electronic Supplementary Material.

## Role of Technology, Socio-economic, and Socio-ecological Feedbacks

Development of a better transportation network including canals and inland waterways in the early half of the nineteenth century, steel-rail network in the latter half of the nineteenth century, and federal highways in the twentieth century, has affected agriculture landscape in the United States (Borchert 1967). Better transportation network has allowed eastern United States markets to be served by agriculture goods produced on the better soils of the Ohio Valley and areas west of the Appalachians (Meyer 1987).

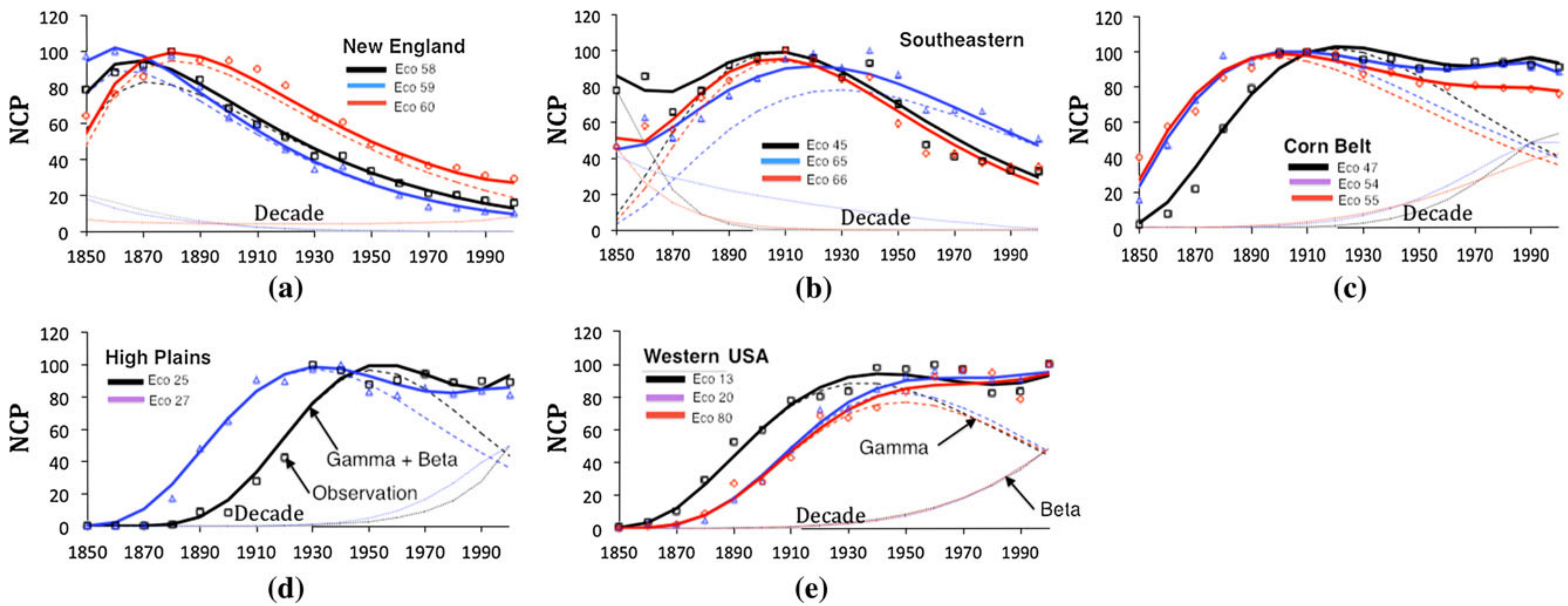


**Fig. 5** The land cover change (cropland) change trajectories in different eco-regions. Three/two representative level-III eco-region's normalized cropland % (NCP = cropland/maximum cropland; Eq. 2) in five regions of the United States are shown: **a** New England. **b** Southeastern United States. **c** Corn Belt. **d** High Plains. **e** Western United States. Regions are shown in Fig. 3a

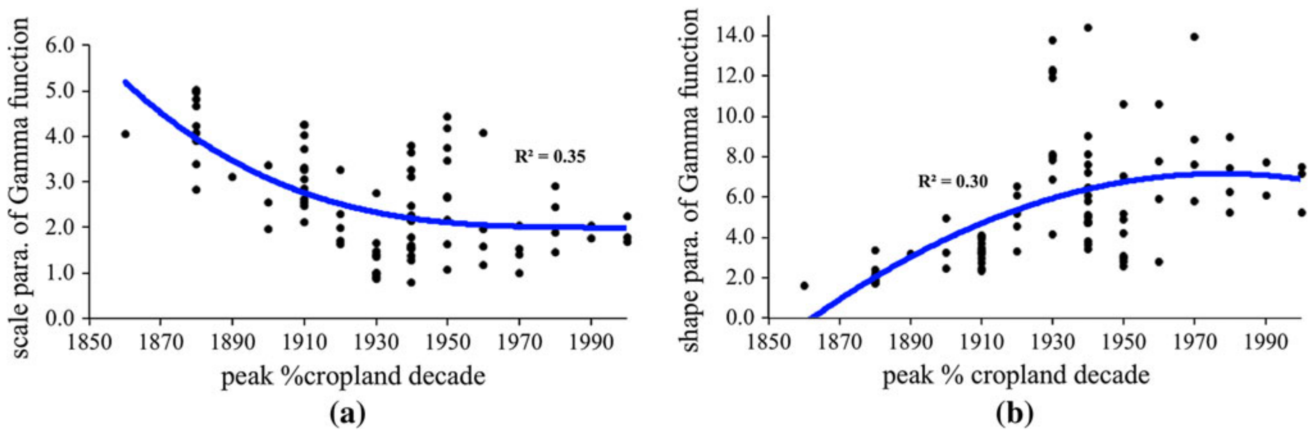


**Fig. 6** **a** The scale parameter (delta) of the gamma function. **b** The shape parameter (alpha) of the gamma function; a higher alpha value represents a slower rate of land conversion

Technological innovations such as chemical fertilizer and mechanization in agriculture in the post World War II period have greatly facilitated agricultural intensification in the United States (Howarth et al. 2002; Dimitri et al. 2005). For example, between 1948 and 2005, agricultural production has increased 2.7 times (Fuglie et al. 2007), while during the same period total cropland area has declined (Fig. 4).

Government policy interventions, such as state drainage laws, and formation of drainage districts, combined with advances in drainage technologies, and market forces transformed the prairies and wetlands of the Midwestern United States into the Corn Belt (Williams 1989, p. 128; Whitney 1994, p. 277). Agriculture in the Western United States is heavily dependent on irrigation projects (Anderson and Woosley 2005). The United States government has implemented the CRP since 1985, in which the farmers are compensated by the government for keeping the environmentally sensitive land idle, or for planting cover crops for environmental protection (e.g., erosion control). Over the last two decades (1990–2010), CRP has operated near to its full capacity (Smith 2000; Hellerstein 2006; Cowan 2010). The total area enrolled under CRP (10 % of total planted area) is three times of the inter-annual variability between 1982 and 2010 (1 standard deviation) in the total planted area (Fig. S.6 in Electronic Supplementary Material).

## DISCUSSION

A quantitative analysis of land cover change and its determinants in the United States is presented. The analysis shows the dynamic behavior of land cover change determinants and the rate of land conversion. As the contribution of the biophysical suitability has monotonically increased during the twentieth century (Fig. 4), it can be hypothesized to be a major determinant in the near future (2010–2050), i.e., the agricultural area will continue to shrink to highly productive land in the twenty-first century; provided crops are grown for food and fiber. However, if crops are grown for biofuels, and demand for biofuels are met in conjunction with demand for food and fiber by bringing marginal land into biofuels production (Pimentel 2003; Tilman et al. 2006); the United States could see another phase of agricultural expansion or shift in agricultural pattern, e.g., corn–soyabean rotation to monoculture corn (Hertel et al. 2008; Mehaffey et al. 2012).

Results of this study are consistent with the theory of increasing agricultural adjustment to land quality (Mather and Needle 1998), and the economic development pathway; farming on low suitability land is not economical, and alternative non-farm jobs are present (Rudel et al. 2005). Interplay between socio-ecological feedback and socio-economic dynamics, suggested by Lambin and Meyfroidt (2010), is also observed. For example, environmental concerns such as erosion control may have triggered CRP, but it has been maintained over last two decades with substantial government support (Cowan 2010).

An overarching influence of technology, transportation, and government policy on the agricultural landscape in the United States is found. The regional differences in demographic composition, government policy, and industrial development have also played an important role. For example, cropland in the Southeastern United States declined after the Civil War (1861–1865), which can be attributed to the loss of cheap labor (Ruef 2004). The freed slaves moved north to the urban centers in search of better employment, and much of the cropland in the Southeastern United States reverted to the managed forests. Similarly, declining cropland trajectory in the Northeastern United

States has been supported by increased industrialization and urbanization (Williams 1989).

We also want to note caveats and possible areas of improvements. Design of this study involving comparison among eco-regions in the same country may have alleviated the issue of uncertainty in the data. Inter-compatibility of data from different countries may pose issue of data quality for a global scale study. Similarly, non-spatial variables in this study, e.g., technology can be spatially non-uniform in a global scale study. For example, differences in technology between developed and developing nations. We also recognize that a functional form other than the combination of gamma and beta can possibly fit to the cropland trajectory. The urban cover model used in this study is rather simplistic. Refinement in biophysical suitability data is needed to incorporate the effect of irrigation (Ramankutty et al. 2002b). In some cases, the contribution of individual determinants (e.g., DI, precipitation, and temperature) may not be important, but when they are combined with other determinants (e.g., soil properties) it can show a significant contribution, e.g., biophysical suitability. Similar combination, if one exists, can be explored for socio-economic determinants.

## CONCLUSION

This study explored the dynamics of land cover change and its determinants in the conterminous United States over the last one and half century. Based on available spatial data, we conclude that the population density was the major determinant of cropland spatial distribution in the nineteenth century, and the biophysical suitability was the major determinant in the twentieth century. In the high biophysically suitable regions, e.g., the Corn Belt, a high-intensity agriculture is sustained. In low biophysically suitable region, e.g., New England, the cropland has declined and the region is urbanized and industrialized. In the Western United States, a low biophysical suitable region, irrigation has played an important role in sustaining a low-intensity agriculture. The rate of land conversion has declined through time. Furthermore, the technological innovation and government policy interventions have played an overarching role for the land cover change in the United States.

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