Telecoupling urbanization and mountainous deforestation between 2000 and 2020: Evidence from Zhejiang Province, China

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Abstract

Forest transition theory posits that socioeconomic development in a country or region may cause its forestland to shift from net loss to net gain. However, forest transition may also occur under various policies, resulting in forest gains in some regions but deforestation in other regions. We used the telecoupling framework to address this crucially important issue that has rarely been examined. Using time series satellite images and statistical yearbook data from 2000 to 2020, this study seeks to understand land use change patterns, the corresponding regional spillover effects, and driving forces behind such patterns in Zhejiang Province, China. The results show that large-scale continuous deforestation has taken place since 2000, causing a total loss of forestland by 186,014 ha. In parallel with this forest loss and a slight decrease in arable land, urban construction land has soared by 169.45%. We found that developed municipalities such as Hangzhou witnessed increases in urban land at the expense of large-scale deforestation in underdeveloped municipalities such as Lishui. We believe that this cross-region land change pattern may arise from the Balance of Arable Land System (BALS) policy that seeks to achieve a goal of no net loss of cropland. Whatever land use policy—such as the BALS policy—must strike a good balance between competitive land uses that have different objectives such as residents' living, ecology, and production. In addition to enriching the forest transition theory, this study provides a solid basis for future land use decisions in developing regions or countries.

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Abstract: Forest transition theory posits that socioeconomic development in a country or region may cause its forestland to shift from net loss to net gain. However, forest transition may also occur under various policies, resulting in forest gains in some regions but deforestation in other regions. We used the telecoupling framework to address this crucially important issue that has rarely been examined. Using time series satellite images and statistical yearbook data from 2000 to 2020, this study seeks to understand land use change patterns, the corresponding regional spillover effects, and driving forces behind such patterns in Zhejiang Province, China. The results show that large-scale continuous deforestation has taken place since 2000, causing a total loss of forestland by 186,014 ha. In parallel with this forest loss and a slight decrease in arable land, urban construction land has soared by 169.45%. We found that developed municipalities such as Hangzhou witnessed increases in urban land at the expense of large-scale deforestation in underdeveloped municipalities such as Lishui. We believe that this cross-region land change pattern may arise from the Balance of Arable Land System (BALS) policy that seeks to achieve a goal of no net loss of cropland. Whatever land use policy—such as the BALS policy—must strike a good balance between competitive land uses that have different objectives such as residents' living, ecology, and production. In addition to enriching the forest transition theory, this study provides a solid basis for future land use decisions in developing regions or countries.

Keywords: deforestation;urbanization;telecoupling;land use policy;Zhejiang Province

1 INTRODUCTION

Anthropogenic activities have altered the Earth's land surface, causing substantial degradation and loss of vital ecosystems and the corresponding services they support (Elhacham, Ben-Uri, Grozovski, Bar-On, & Milo, 2020). Land use and cover change under human modification has greatly transformed the Earth's energy balance and biogeochemical cycles, which contribute to climate change and biodiversity degradation and in turn affect the nature of the land surface and the provision of ecosystem services (Foley et al., 2005; Turner, Lambin, & Reenberg, 2007). Humans depend on land for food, energy, living space, and socioeconomic development (X. P. Song et al., 2018). With a rapidly growing population, the demand for natural resources has increased drastically worldwide (Foley et al., 2011), resulting in widespread degradation and reduction of ecosystem services (Pandit et al., 2019). To effectively cope with these global challenges, the United Nations has crafted 17 Sustainable Development Goals (SDGs), among which Goal 15 of halting and reversing land degradation mostly pertains to future land planning. However, taking the SDG agenda seriously and implementing it on the ground will be far from easy (Jianguo Liu et al., 2018). With large-scale biodiversity loss and degradation due to unsustainable land development, deforestation, and infrastructure expansion, a set of undesirable consequences-such as the COVID-19 pandemics—may arise and beset mankind (Dobson et al., 2020; Tollefson, 2020).

Rapid urbanization will encroach cropland around municipalities, leading to large-scale loss of arable land. Since the turn of the 21st century, China has stepped into a critical era of rural-urban transition. Widespread and accelerated urbanization has made land resources increasingly scarce, representing a serious challenge to a country like China with a huge population base (Jiang, Deng, & Seto, 2012; J. Liu et al., 2007). During the process of urbanization, built-up land is tremendously expanding (E. F. Lambin et al., 2001), seriously affect food production and consumption systems (Godfray et al., 2010). The cascading effects of such changes may pose an even greater challenge to cropland conservation and thus food security (Davis et al., 2016), leading to deforestation at larger scales, overuse of fertilizer, and other environmental problems (Costello et al., 2020; E. F. Lambin et al., 2001; Long, Zou, Pykett, & Li, 2011; Tan, Li, Xie, & Lu, 2005).

The land use transition theory has been proposed to illustrate land change trajectories in the process of socioeconomic development, which can be used to explain the global pattern related to forest net gain (Eric F. Lambin & Meyfroidt, 2011). Topologies of land use transition includes forest loss (DeFries, Rudel, Uriarte, & Hansen, 2010), rural housing land transition (T. Li, Long, Liu, & Tu, 2015; Long, Heilig, Li, & Zhang, 2007), cropland transformation (Long & Li, 2012; W. Song & Deng, 2015), urban land expansion (Gao, Huang, He, Sun, & Zhang, 2016), and so on. The land use transition theory offers theoretical and technical support for the rational use of natural resources and land (E. F. Lambin & Meyfroidt, 2010; Long & Qu, 2018). With rural-to-urban migration over large scales accompanying urbanization, sustainable use of land becomes a central concern of policy-makers and other stakeholders (Long et al., 2018). The accelerated urbanizing process has triggered a dramatic shift in land use in China, which has been a hot topic of research for many years (Long, 2014).

Maintaining an adequate amount of arable land is a prerequisite for securing food production (Chaplin-Kramer et al., 2015; Foley et al., 2011). Arable land has multifunction, ranging from food production, to social security, and to ecological services (Long, 2020). To ensure food security, China's central government has executed a series of policies to hold arable land from loss, including the Balance of Arable Land System (BALS) policy, the Basic Cropland Protection System program, and the policy to couple the increase of Urban Construction Land with Reducing Rural Construction Land (Long, Li, Liu, Woods, & Zou, 2012; Shen et al., 2017; Wei Song & Pijanowski, 2014). A common goal of these policies is to maintain the amount of arable land by relocating arable land from adjacent urban areas to remote rural places (Xin & Li, 2018), which may destroy or downgrade the environment in the latter (Y. Liu, Feng, Zhao, Zhang, & Su, 2016). However, the effectiveness of these polices and their impacts on social ecological systems in related areas have not been fully explored. Previous studies have shown widespread deforestation in Zhejiang Province (Xiong, Chen, Xia, Ye, & Anker, 2020) even after the proposed national strategy of ecological protection and ecological civilization. Therefore, more work is needed to understand how these policies caused widespread land degradation.

Institution is a key driver of land change (Stuhlmacher, Turner, Frazier, Kim, & Leffel, 2020). Land use change is influenced by both policy and socioeconomic development in China (Wang, Lin, Glendinning, & Xu, 2018) and elsewhere (Halbac-Cotoara-Zamfir, Keesstra, & Kalantari, 2019). Under China's accelerated urbanization, land use transformation is mainly represented by the shrinkage of cultivated land and the expansion of construction land at rural-urban fringe areas (Y. S. Liu, Wang, & Long, 2010; Su, Zhou, Wan, Li, & Kong, 2016). Exploring the institutional dimension of land use change may not only contribute to finding solutions for sustainable land use, but also help reform ineffective land use policies (Long et al., 2018). In the present research, we analyze the land use dynamic in Zhejiang Province from 2000 to 2020 using Hanson's deforestation datasets and Globeland30 remote sensing datasets in conjunction with data from statistical yearbooks and other sources. We aim to reveal: (a) the deforestation process and its linkage to other types of land use change in Zhejiang Province; (b) policy factors that have driven deforestation; (c) the relationships between deforestation and urbanization; and (d) the mechanism in relation to how urbanization in one region has resulted in deforestation in other distant places. This study attempts to contribute to understanding land use change patterns in Zhejiang Province in the context of urbanization, their regional spillover effects, and the corresponding driving forces. In recognition of the challenges related to the "no net loss" policy at large, we aim to promote effective measures towards the goal of sustainable use of land.

2 METHOD AND MATERIALS

2.1 Study area

Zhejiang Province, one of the most socioeconomically developed provinces in China, is chosen to be our study area for the following reasons. Located at the southeastern coast of China, Zhejiang is located at the southern fringe of the Yangtze River Delta (Figure 1). Lying between 27°12´-31°30´N and 119°42´-122°06´E, it has a subtropical monsoon climate with abundant rainfall (1,100 to 2,000 mm on average annually). With a land area of 10,550,600 ha, Zhejiang is a mountainous province characterized mostly by mountains (˜70%), agricultural land (˜20%), and water body (˜10%), with flat areas mainly in the northeast and mountainous areas in the southwest (Figure 1). As of the end of 2019, the total population was 58.5 million, of which 70% lived in cities, where the forest coverage was 61.15% of the total land area (citation from Zhejiang Statistical Yr book). Zhejiang province, with a GDP of 954 billion USD and GDP per capita of 16,474 USD in 2019, ranks the fourth and the fifth in China's 31 provinces, respectively. The geographical diversity and rapid economic development have led to fundamental changes in land cover and land use. Recently, deforestation associated with urbanization has become a serious problem, which renders Zhejiang Province an ideal case study area for conducting research on policy related deforestation.

Figure 1. Location and Elevation of Zhejiang Province, China

2.2 Data sources and processing

We utilized primarily GlobeLand30 to detect and analyze land use changes in Zhejiang Province from 2000 to 2020. GlobeLand30 is the first open-source, fine-scale global land cover database based on remote sensing models (J. Chen et al., 2015). This dataset is the only product worldwide on land cover with a 30 meters resolution for the years of 2000, 2010 and 2020. The GlobeLand30 dataset is derived from over 20,000 Landsat and HJ-1 (China Environment and Disaster Reduction Satellite) imageries using machine-learning models in combination with pixel-level and object-based processing procedures. In particular, the dataset of 2020 also incorporates the 16-meter resolution GF-1 (China High Resolution Satellite) multispectral images. The principle of image selection in the dataset is to select multispectral images of the vegetation growing season within ± 2 years of the baseline year in which the data were generated and updated, provided that the images are cloud-free or with least cloud. For areas that are difficult to acquire data, the timing of image acquisition can be adjusted to ensure the integrity of the overall coverage. The classification scheme includes 10 land cover types, which are agricultural land, forest land, grassland, shrub land, wetland, water body, tundra, artificial surface, bare land, and perennial snow and ice, with no mosaic pixels (J. Chen et al., 2015).

Based on a third-party evaluation, the overall accuracy of classification based on GlobeLand30 (for 2010) is 83.50% and the Kappa coefficient is 0.78. This result is from validation effort based on over 150,000 points in 80 tiles of 853 in total. On the other hand, the overall accuracy of classification based on GlobeLand30 (for 2020) is 85.72% and the Kappa coefficient is 0.82 according to our validation results based on over 230,000 points from the whole datasets using landscape index sampling model (Jun, Ban, & Li, 2014; Liang et al., 2015).

To better analyze the results of land use change in Zhejiang Province, we also used data from Zhejiang Land Statistics Yearbook. Specifically, we analyzed official statistics on land use change in Zhejiang Province since 2000. To more comprehensively capture forest loss in Zhejiang Province, we also selected the European Space Agency (ESA) - Climate Change Initiative (CCI) as another data source. With a medium-resolution (300m) resolution, the dataset has a global coverage from 2000 to 2018, which classified pixels (using a machine-learning algorithm) into over 22 land cover categories (for instance, mosaic natural vegetation of tree, shrub, herbaceous vegetation) (Bontemps et al., 2013). The accuracy of the map is reported to be 71.5% (Defourny et al., 2017). In our study, we reclassified the products according to the IPCC classification criteria and extracted the forest class for further analysis; here for alignment with our land classification typology, all ESA-CCI land cover types with trees and mosaic trees and shrubs were reclassified as forestland.

To further assess the annual change regarding forest loss, we used the latest version (Version 1.7 Update) of Hansen's forest cover dataset, which is available online on the Google Earth Engine (GEE) website and the Global Forest Watch website. The most updated dataset contains the layers of 2000 tree canopy cover and 2001-2019 forest loss, providing the information regarding the year of forest loss. The product has a 30m spatial resolution and is synthesized by processing 654,178 Landsat 7 ETM+ images in high quality (Hansen et al., 2013). The dataset defines trees as "all vegetation above 5m in height" and forest loss as "the mortality or removal of all tree covers in a 30m by 30m pixel" (Hansen et al., 2013). Hansen's previous update of forest gain was in 2012 and thus may be biased from forest growth in reality. The overall accuracy, assessed by the Food and Agriculture Organization (FAO) statistics using both LiDAR surveys and other satellite data, has been shown to be over 99% (Hansen et al., 2013). In order to minimize any data error and improve classification accuracy, we have combined remote sensing datasets with field surveys. The validation results turned to be fairly good: we have achieved an overall accuracy of 80% based on Hanen's data in Zhejiang Province (Xiong et al., 2020). In addition, we believe that the next generation of Hansen products (e.g., Version 2.0) may provide more information on actual forest growth and loss (Zeng et al., 2018). In this assessment, by referring to the Global Forest Watch website, we set 30% as the threshold of defining the canopy cover for all the following analyses of forest loss.

The administrative division data of Zhejiang provincial is derived from Global Administrative Areas (GADM). These datasets have their own strengths in showing the spatial and temporal patterns of land change in Zhejiang Province (Table 1), and the combined use of the results of these data analyses is beneficial in exploring the spatial and temporal characteristics of land use transformation.

Table 1. Different land data sources

Data	Period	**Spatial Resolution**	**Temporal Resolution**	**Data Sources**
GlobeLand30	2000/2010/2020	30 m	/	http://www.globeland30.org/
Hansen v1.7	2001–2019	30m	Annually	http://earthenginepartners.apps
ESA-CCI	2000-2018	300m	/	http://www.esa-landcover-cci.or
Statistical yearbook	2000-2018	/	Annually	https://data.cnki.net/
GADM	Up to date	/	/	https://gadm.org/download_cou

RESULTS

3.1 Deforestation in Zhejiang Province

Figure 2. Temporal changes and spatial patterns of deforestation in Zhejiang Province from 2000 to 2020. (a) Cumulative forest loss (line) and annual loss (bar) from 2001 to 2019. (b) Scale of forest change. The bar charts are estimates based on satellite-based land-cover change products and statistical yearbook data (GlobeLand30, 2000–2020; ESA-CCI, 2000–2018; Statistical yearbook, 2000-2018). (c) Spatial distribution of net forest loss converted to other land classifications from 2000 to 2020. (d) Spatial distribution of net forest gain derives from other land classifications from 2000 to 2020

Our estimation based on the Hansen's datasets shows that the total net loss of forest cover in Zhejiang Province from 2001-2019 is 279,501 ha (Figure 2a), a 4.7% decline in forest from the 2000 baseline. Annually, the rate of forest loss is about 12,549 ha per year during 2001-2008, representing an six-fold increase from about 4,245 ha in 2001 to nearly 26,993 ha in 2008. After 2008, the forest loss appeared to be stable during 2009-2019, but at a high rate of 16,282 ha each year. The cumulative forest loss monotonically increased during the entire study period.

In addition to the Hansen's dataset, other data products including Globeland30 and ESA-CCI also show forest loss in Zhejiang Province after 2020 (Figure 2b). The Globeland30 dataset shows that forest cover decreased by 22,823 ha in Zhejiang during 2000-2020 and ESA-CCI 186,014 ha during 2000-2018, but Zhejiang's statistical yearbook data show an increase in forest at the magnitude of 80,400 ha in Zhejiang from 2000-2018 (Figure 2b). We believe that remote sensing based land change results do not rely on government statistics and have higher spatial resolutions, are thus more likely to be less biased.

At the same time, we analyzed the spatial distribution of forest loss and gain in Zhejiang Province using GlobeLand30 high-resolution satellite images (Figure 2c and d). Over the space of Zhejiang Province, forest loss was found to be a prevalent phenomenon in many parts across the whole province. The landscape in terms of forest loss was shown to be scattered and rarely interconnected in general, but forest loss mainly dominated the mountainous regions within the province (Figure 2c). Overall, forest loss happened mainly in western and southern parts of Zhejiang, while the lost area was relatively small in the northeastern part. Forest loss exhibited heterogenous patterns at the municipality level (Figure 2c). Among all the municipalities in Zhejiang Province, the greatest loss in forest cover was observed in Lishui municipality in South Zhejiang, which is followed by Hangzhou municipality in West Zhejiang (the most economically developed city and the capital city of the province). Jiaxing municipality in proximity to Shanghai (the economic center in eastern China) possessed the least loss of forest. Forest loss was mainly due to conversion to cropland, with the largest amount occurring in Lishui.

Forest gain also occurred in almost all areas of Zhejiang Province. But the increase in forestland in most of those regions was less than the loss of forests. Among all the municipalities, Hangzhou has the largest increase and Jiaxing the smallest increase. The main source of forest gain is through converting cultivated land to forest, which is observed most in Wenzhou, followed by Lishui and Hangzhou (Figure 2d).

3.2 Urban expansion in Zhejiang Province

Figure 3. Temporal changes and spatial patterns of urban land in Zhejiang Province. Data of temporal change of land use are from (a) Statistical Yearbook between 2000-2018 and (b) GlobeLand30 between 2000-2020. (c) Spatial distribution of net forest loss converted to other land classifications from 2000-2020. (d) Spatial distribution of net forest gain derives from other land classifications over the same time span

According to a statistical yearbook (2001-2018) (Figure 3a), the proportion of urban area in Zhejiang Province increased steadily between 2001 and 2018. During the same period, the proportions of urban land area and forest land area increased by 70.29% and 1.45%, respectively, while the arable land area decreased by 5.26%. The rest of land types had a gradual decrease (Figure 3a). Using the Globeland30 data, we found that during 2000-2020, the area of urban land use increased by 169.45% while the area of forest and arable land decreased by 0.40% and 19.20%, respectively (Figure 3b).

Meanwhile, we used GlobeLand30 to analyze the spatial distribution of urban land changes in Zhejiang Province (Figure 3c and d). Spatially, urban area loss and gain occurred in almost all over the province, but the lost patches were dispersed and much smaller compared to the gained areas although the amount of net loss is only around 6% of the net gain. Of these, Ningbo and Hangzhou had the largest urban area gains, while Lishui and Zhoushan had the smallest gains (Figure 3c and d).

Figure 4. Sankey Map of Land use Transformation in Zhejiang Province from 2000 to 2020

The largest land use changes from 2000 to 2020 took place in the form of land use conversions between urban construction land, arable land, and forest in Zhejiang Province (Figure 4). The conversion from arable land to urban area is the largest (562,399 ha), followed by conversions from arable land to forest land (260,322 ha) and from forest land to arable land (210,474 ha). The changes in other land uses are relatively small. It seems that urban land expansion primarily comes from losses of arable land, while arable land increases as a result of deforestation.

3.3 Linkages of deforestation and urbanization: Lishui and Hangzhou

Figure 5. Land use change in Hangzhou and Lishui from 2000 to 2020

By comparing the land use change patterns of Hangzhou and Lishui, we found that the largest conversion from cultivated land to urban area in Hangzhou was 77,288 ha, followed by 37,036 ha from cultivated land to forest land and 26,551 ha from forest land to cultivated land. In Lishui, the maximum conversion was 37,198 ha of cultivated land to forest land, 36,787 ha of forest land to cropland, and only 16,910 ha of cultivated land to urban area. These results show that the biggest land change in Hangzhou is from cultivated land to urban land. The change in Lishui municipality is mainly due to conversion between cropland and forest land, and its area of forestland loss is larger than that of Hangzhou municipality (Figure 5).

Figure 6. Socioeconomic change in Hangzhou and Lishui municipality of Zhejiang Province from 2000 to 2019

Hangzhou's GDP continued to increase from 138.256 to 1537.305 billion yuan during 2000-2019, representing an 11-fold increase. The resident population of Hangzhou municipality increased by 148% from 7.02 to 10.36 million. Lishui's GDP, on the other hand, only increased from 13.676 to 147.661 billion yuan during 2000-2019 with a slow resident population growthfrom 2.16 to 2.21 million (Figure 6).

Figure 7. Telecoupling of deforestation and urbanization in Hangzhou and Lishui

Considering the representative land use change in Hangzhou and Lishui municipalities, they illustrate an ideal case for demonstrating the telecoupling concept (Jianguo Liu, 2017; Sun Jing et al., 2020). In Zhejiang Province, Hangzhou is the most urbanized municipality while Lishui is comparatively less urbanized. As Hangzhou's urban population increased, its limited land resources can no longer meet the needs of the region's urbanization. Therefore, urban expansion inevitably took arable land resources from surrounding areas, leading to a reduction in arable land area. The governments could enact policies to find back-up land resources through the role of an intermediate agent (such as a higher-level government). The municipality of Lishui, however, has sufficient back-up land resources due to its lower level of economic development, massive out-migration of rural population, and slower urban development. Through the role of an agent, a local government can supply its reserved land resources to meet the need of other areas in need of land supply. Land and money may be exchanged between two such regions in the form of flows to get what each need. For instance, Hangzhou may buy back-up land resources from Lishui for urbanization, whereas Lishui could receive a corresponding compensation. Meanwhile, Lishui may also suffer from land degradation and loss of ecosystems in the region as a result (Figure 7).

4 DISCUSSION

4.1 Causes of deforestation in Zhejiang Province

Zhejiang Province has experienced massive deforestation since 2000, representing a significant land use change in the region. During the study period, remote sensing data showed a decrease in forest area in Zhejiang Province between 2000 and 2020.

According to satellite-based land use and land cover products, we detected a substantial decrease in forest area in the early 2000s (Figure 2b). While data on forest decline are not uniform, inconsistent definition of forest may be a plausible reason for explaining the different rates of forest loss among various land cover products (H. Chen et al., 2020; Zeng et al., 2018). The Hansen's forest dataset show that extensive deforestation occurred in Zhejiang Province in the early 2000s (Xiong et al., 2020). However, the GlobeLand30 (30 m) imagery, which has a higher resolution, showed less deforestation compared to the Hansen's dataset. The GlobaLand30 dataset was produced with a globally trained machine learning algorithm. This algorithm, less suitable for detecting irregularly shaped mountain crop fields, may account for its underestimation of forest loss. The resolution of the ESA-CCI (300m) product requires a classification scheme to use mosaic classes, which might result in mixing cropland with other land cover types. These mosaic categories may also underestimate the area of agricultural land (Ozdogan & Woodcock, 2006), and thus may also have underestimated forest loss. Yet, despite the inconsistent changes in forest loss area, we believe that remotely sensed land data, not relying on government statistics, are more likely to show objective patterns with relatively high reliability (Zeng et al., 2018).

Forest transition theory assumes that forest in a country or a region will shift from a net loss to a net gain along with socio-economic development (Meyfroidt, Rudel, & Lambin, 2010). However, it has also been shown that if a country or region is engaged in cross-region trade flows (e.g., South America soybean), then deforestation may positively correlate with the growth of urban population and agricultural exports (DeFries et al., 2010). Some studies also show that forestland tends to be lost as China's GDP per capita rises (Vina, McConnell, Yang, Xu, & Liu, 2016). The accelerated urbanization in Zhejiang Province from 2000 to 2020 has resulted in conversion from agricultural land to urban land (Figure 4). Besides, we also observed a large amount of forest loss (i.e., land converted to arable land) (Figure 4) and continued forest fragmentation in Zhejiang Province, which might arise from reclamation of agricultural land (Xiong et al., 2020). Such large-scale and rapid deforestation should be of concern to governments and the scientific community.

4.2 Policy evolution on the Balance of Arable Land System (BALS)

The establishment and implementation of the BALS policy, established to play a dual role of guaranteeing economic development and protecting the environment, might have achieved this goal (Long et al., 2012; Xin & Li, 2018). However, this policy also attracted great debate and was changed several times.

China's BALS policy can be roughly divided into three stages (Figure 8). The initial stage was for systematic policy construction. China first proposed the arable land acquisition and compensation system in 1997. The BALS policy was formally written into the new Land Management law in 1998. To protect arable land, China amended the Land Management Law to maintain the amount of arable land with a new arable land replenishment mechanism, giving rise to the "occupy one ha and replenish one ha" policy in 1999. In 2001, all provinces (including autonomous regions) basically achieved a balance in the amount of arable land, ensuring that the total area of arable land was not in decline. The focus of land consolidation during this period was to increase the amount of arable land, provide space for urbanization and industrialization, ensure food security, and increase farmers' income (Wei Song & Pijanowski, 2014).

Figure 8. The Balance of Arable Land System (BALS) policy evolution

The second stage featured systematic policy improvement. From 2004 onwards, Chinese government has been focusing on the quality of newly created arable land, issuing a series of policies. In 2004, the government introduced measures to control the quality of land during land conversions, assuring that the quantity and quality of newly created arable land should meet national standards. The year of 2005 saw a shift of focus to administrative accountability, starting to implement an accountability target assessment and chief executive responsibility system. In 2006, several specific institutional assessment mechanisms were introduced, which issued several pilot projects demanding that decreases in rural construction land be linked to increases in urban construction land (Long & Li, 2012). In 2008, China proposed to designate permanent basic cropland to ensure that the quantity of arable land would not be reduced and its quality would be improved. In 2009, arable land was required to be fully replenished before land occupation, and subsequent operational rules were issued to strengthen the quality and management of replenished arable land. At this stage, the quantity and quality of arable land was protected, and the productivity of arable land was relatively ensured (Long, 2020).

The third stage was characterized by a "Trinity" of quantitative, qualitative, and ecological policy. The Chinese government authorities have further improved their management approach by emphasizing a policy of balancing land occupation and compensation between provinces. To ensure the quality of replenished arable land, a decree was issued in 2012 to strengthen the management of arable land and maintain land quality. In 2014, the Chinese government proposed that the occupation of high-quality land and paddy land should be compensated; in 2016, a combination of quality improvement and remediation was proposed. In 2018, China formed the Ministry of Natural Resources to strengthen the unified integration and management of natural resources. In 2018, the Ministry of Natural Resources issued a national coordinated management decree to establish the inter-provincial replenishment of arable land along with a management scheme for construction land transfer between rural and urban areas in different provinces. This provides a clear direction for the unified management of arable land resources, focusing more on the ecological functions of land use (Long, 2020; Long et al., 2018).

Zhejiang Province, the first province to implement the BALS policy in China, needs to evaluate its consequences and effectiveness. It is easy to focus on assessing the quantitative balance and difficult to assess the qualitative and ecological balance (Lin et al., 2017). As cropland varies greatly over spatial and temporal dimensions, the policy needs to be further adjusted in the future to effectively protect high-quality cropland resources and support national food security and ecological safety. In Zhejiang, for example, the conversion of forestland to agricultural land has occurred in parallel with the BALS policy implementation, inevitably leading to loss of forestland (Xiong et al., 2020).

4.3 Telecoupling and the no net loss of cropland policy

The telecoupling framework can explain the long-range land change mechanisms (Jianguo Liu, 2017; Sun Jing et al., 2020), which may apply to this particular deforestation phenomenon in Zhejiang Province. The expansion of arable land, although able to satisfy market demands and conform with policies, may lead to ecological problems such as deforestation (Henders, Ostwald, Verendel, & Ibisch, 2018). Our study shows that the largest source of urban construction land in Zhejiang Province is arable land, and the largest source of arable land is through converting forest land (Figure 4). In the context of the BALS policy, the balance of cropland quantity needs to be guaranteed, which inevitably leads to converting forest land to arable land in Zhejiang Province. In China, large municipalities like Hangzhou are often blamed for the massive loss of high-quality arable land (Hu et al., 2020). The largest land change in Hangzhou is the conversion of arable land to urban land; while in Lishui, the major changes feature mutual conversions between arable land and forest land with the area of forestland loss larger than that in Hangzhou (Figure 5). The less-urbanized Lishui municipality also has the most deforested area in Zhejiang Province (Xiong et al., 2020). A stable or depopulated landscape may face a higher deforestation pressure largely because distant urbanization processes would demand increases in arable land in surrounding places. In contrast, the BALS policy allows for the deployment of land resources within the province. In this context, Lishui municipality becomes the place that supplies land resources for other cities and towns because of its lower level of urbanization. As a result, Lishui will likely experience land degradation and ecosystem loss.

Figure 9. Mutual relationships between productive, living, and ecological land

The simultaneous demand of land for urban development, ecological conservation, and rural revitalization is a challenge for China's policy and planning for land and other related resources (R. Chen, Ye, Cai, Xing, & Chen, 2014). A rational land planning and management system needs to reconcile the balance among productive land, living land, and ecological land (Figure 9). However, many land use policies implemented in China for more than 20 years are irrational in some aspects as they do not coordinate well with each other. These policies have either failed to ensure the productivity of arable land, or resulted in ecological land degradation, which clearly contradict China's strategy for sustainable development (Bryan et al., 2018). Moreover, appropriate land use policies must be in line with socioeconomic development (Xin & Li, 2018). With urbanization, the continuing migration of rural population to cities will inevitably lead to the emergence of hollow villages and the abandonment of large amounts of arable land in rural areas (Zhang, Song, & Chen, 2018), which will further challenge the effectiveness and efficiency of BALS (S. Li et al., 2018).

5 CONCLUSIONS

Forest loss has taken place in many areas of the world. Understanding the spatial and temporal patterns of forest loss may not only advance the forest transition theory but also provide practical guidelines for preventing land degradation and promoting sustainable socioeconomic development. The present study draws on datasets from multiple sources to investigate land use change with an emphasis on forest change in Zhejiang Province during 2000-2020 under the implementation of the Balance of Arable Land System (BALS) policy. The investigation found that there was a large decrease of forest area during the study period, which is accompanied by expansion of urban land and shrinkage of cultivated land. At the sub-provincial scale, such land use conversions among different types induced by BALS occurred not in adjacent areas but in distant places.

By relying on the telecoupling framework, we are able to better explain land use and land cover change patterns and mechanisms. Using the Hangzhou (west) and Lishui (south) municipalities as an illustration, the encroachment of cultivated land by urban development in Hangzhou has been "compensated" through agricultural expansion at the sacrifice of deforestation in Lishui, according to the principle of balancing cultivated land in BALS. This finding empirically supports the telecoupling theory. Under this framework, BALS has evolved from focusing on quantity protection to focusing on the "Trinity" of quantity, quality, and ecological protection. Policymakers should be mindful of forest losses and mechanisms behind such losses while designing and implementing land-based policies and planning, especially those involving societal and economic development and agricultural protection. By fully considering the patterns of multiple land types (e.g., urban, cropland, ecological land) and their relationships (e.g., the telecoupled interconnections), can a more comprehensive land use policy be sophistically designed and appropriately executed to reach the harmony among promoting development, securing food production, and preventing land degradation. At broader scales, this study further enriches the theory of forest transition, providing a basis for future land use policies or decisions.

ACKNOWLEDGMENTS

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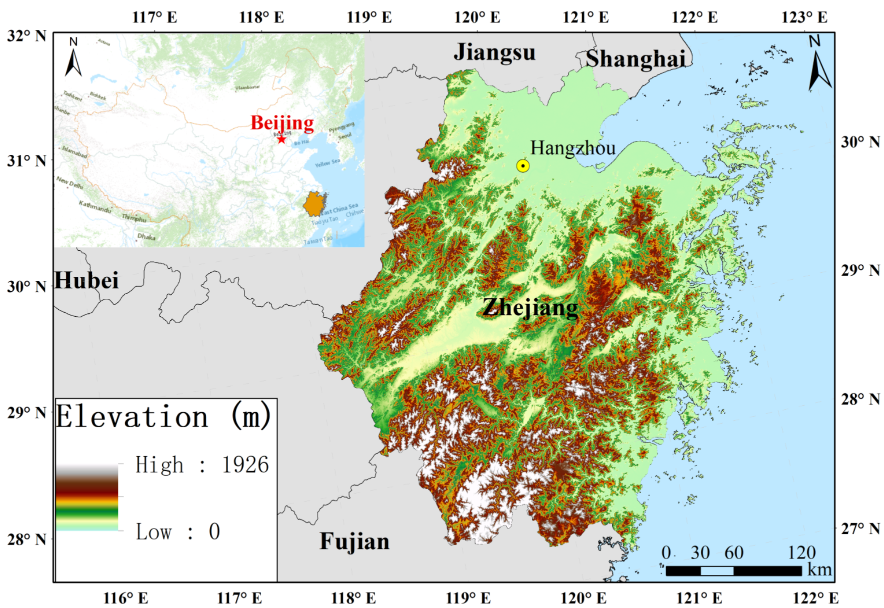
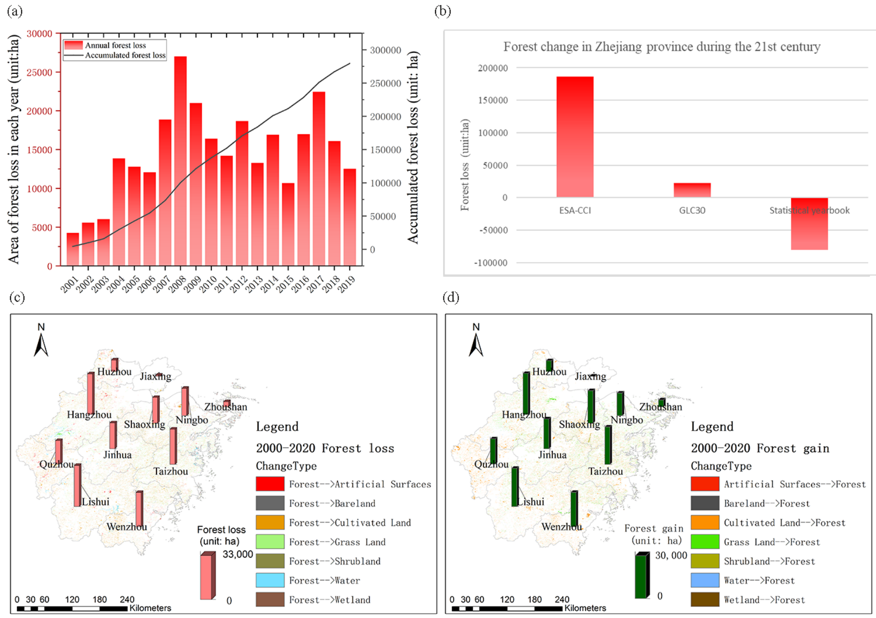
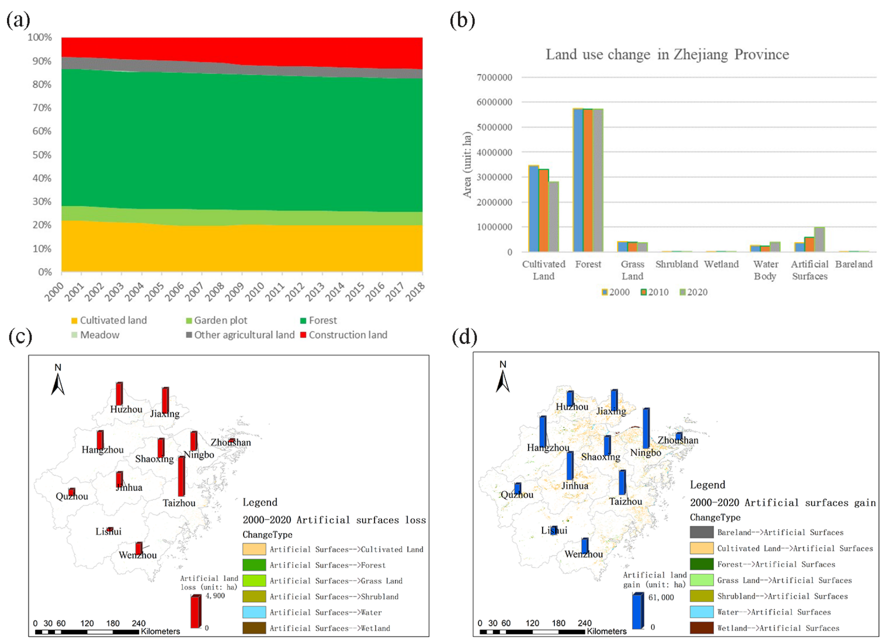
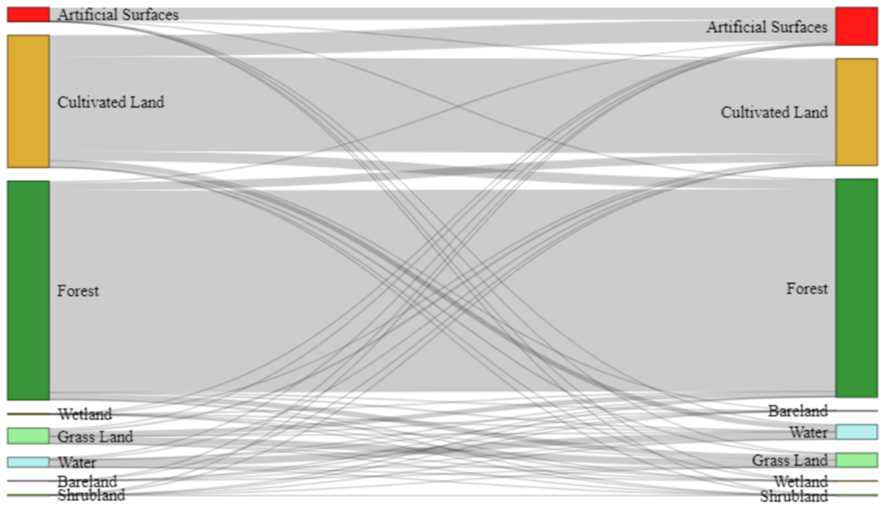
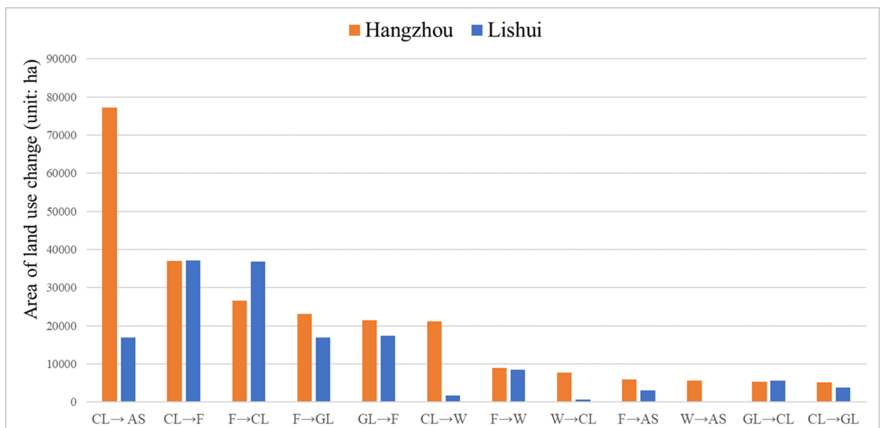


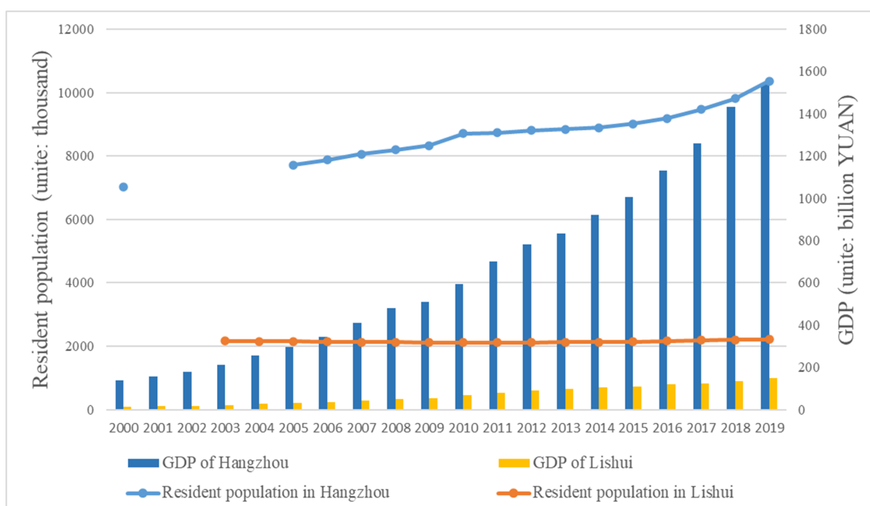

(a)
Annual forest loss
Accumulated forest loss
Area of forest loss in each year (unit:ha)
Accumulated forest loss (unit: ha)
(b)
Forest change in Zhejiang province during the 21st century
Forest loss (unit:ha)
ESA-CCI
GLC30
Statistical yearbook
(c)
Huzhou
Jiaxing
Zhoushan
Hangzhou
Shaoxing
Ningbo
Jinhua
Quzhou
Taizhou
Lishui
Wenzhou
Legend
2000-2020 Forest loss
ChangeType
Forest-->Artificial Surfaces
Forest-->Bareland
Forest-->Cultivated Land
Forest-->Grass Land
Forest-->Shrubland
Forest-->Water
Forest-->Wetland
Forest loss (unit: ha)
33,000
Kilometers
(d)
Legend
2000-2020 Forest gain
ChangeType
Artificial Surfaces-->Forest
Bareland-->Forest
Cultivated Land-->Forest
Grass Land-->Forest
Shrubland-->Forest
Water-->Forest
Wetland-->Forest
Forest gain (unit: ha)
30, 000
Kilometers

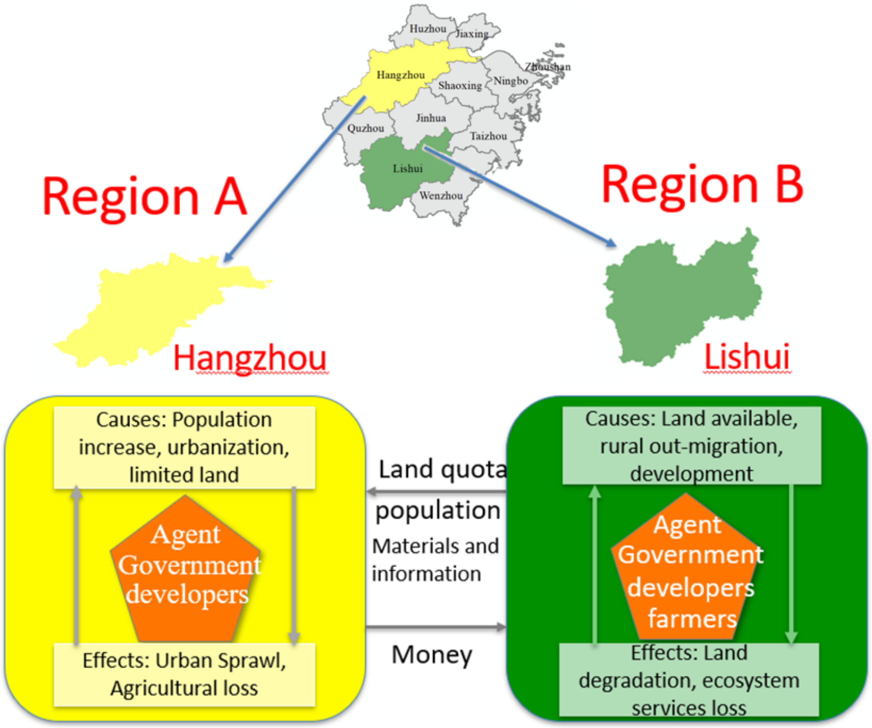

(a)
Cultivated land
Garden plot
Forest
Meadow
Other agricultural land
Construction land
(b)
Land use change in Zhejiang Province
Area (unit:ha)
Cultivated Land
Forest
Grass Land
Shrubland
Wetland
Water Body
Artificial Surfaces
Bareland
2000
2010
2020
(c)
Legend
2000-2020 Artificial surfaces loss
ChangeType
Artificial Surfaces-->Cultivated Land
Artificial Surfaces-->Forest
Artificial Surfaces-->Grass Land
Artificial Surfaces-->Shrubland
Artificial Surfaces-->Water
Artificial Surfaces-->Wetland
Artificial land loss (unit: ha)
4,900
Kilometers
(d)
Legend
2000-2020 Artificial surfaces gain
ChangeType
Bareland-->Artificial Surfaces
Cultivated Land-->Artificial Surfaces
Forest-->Artificial Surfaces
Grass Land-->Artificial Surfaces
Shrubland-->Artificial Surfaces
Water-->Artificial Surfaces
Wetland-->Artificial Surfaces
Artificial land gain (unit: ha)
61,000
Kilometers

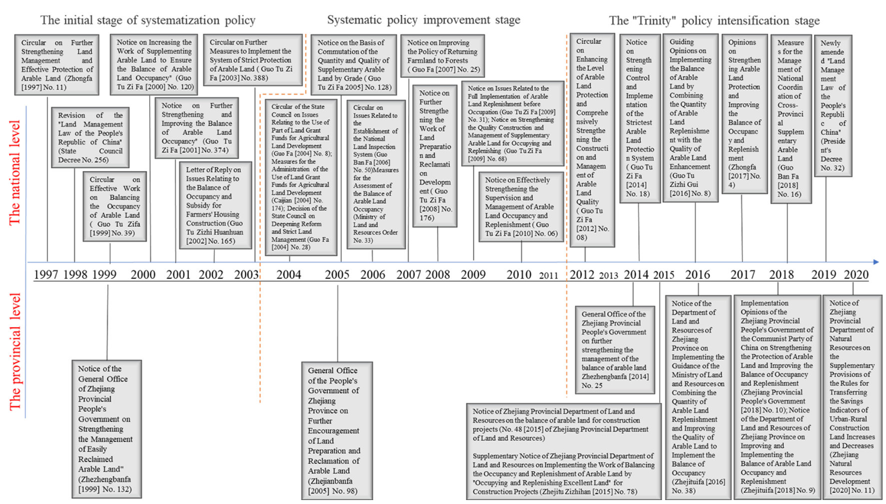


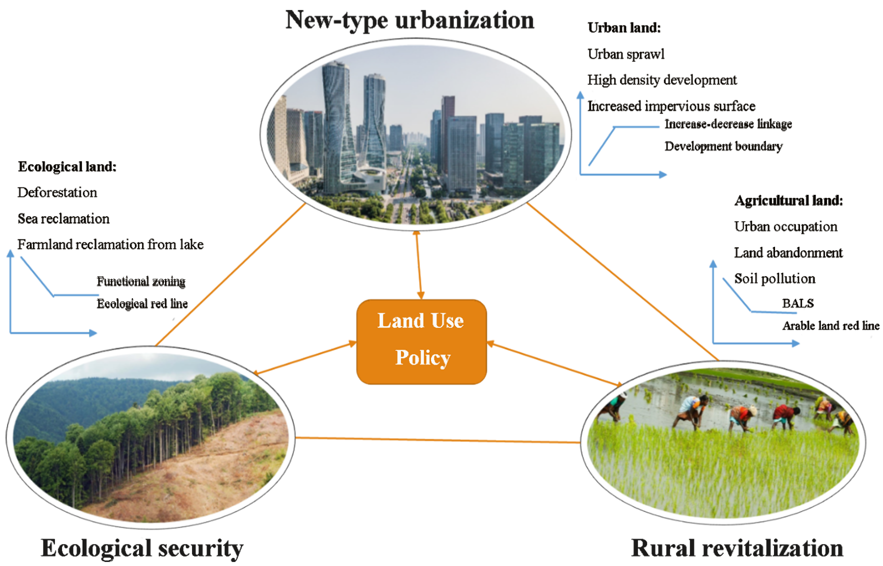


Note: CL is Cultivated Land, AS is Artificial Surfaces, F is Forest, GL is Grass Land, W is water.




Huzhou
Jiaxing
Hangzhou
Shaoxing
Ningbo
Zhoushan
Quzhou
Jinhua
Taizhou
Lishui
Wenzhou
Region A
Region B
Hangzhou
Lishui
Causes: Population increase, urbanization, limited land
Agent Government developers
Effects: Urban Sprawl, Agricultural loss
Land quota
population
Materials and information
Money
Causes: Land available, rural out-migration, development
Agent Government developers farmers
Effects: Land degradation, ecosystem services loss


The initial stage of systematization policy
Systematic policy improvement stage
The "Trinity" policy intensification stage
The national level
The provincial level
1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020


New-type urbanization
Urban land:
Urban sprawl
High density development
Increased impervious surface
Increase-decrease linkage
Development boundary
Ecological land:
Deforestation
Sea reclamation
Farmland reclamation from lake
Functional zoning
Ecological red line
Agricultural land:
Urban occupation
Land abandonment
Soil pollution
BALS
Arable land red line
Land Use Policy
Ecological security
Rural revitalization