



The positive impacts of landscape fragmentation on the diversification of agricultural production in Zhejiang Province, China

Article

Accepted Version

Creative Commons: Attribution-Noncommercial-No Derivative Works 4.0

Qiu, L., Zhu, J., Pan, Y., Wu, S., Dang, Y., Xu, B. and Yang, H. (2020) The positive impacts of landscape fragmentation on the diversification of agricultural production in Zhejiang Province, China. *Journal of Cleaner Production*, 251. 119722. ISSN 0959-6526 doi:

<https://doi.org/10.1016/j.jclepro.2019.119722> Available at <http://centaur.reading.ac.uk/88505/>

It is advisable to refer to the publisher's version if you intend to cite from the work. See [Guidance on citing](#).

To link to this article DOI: <http://dx.doi.org/10.1016/j.jclepro.2019.119722>

Publisher: Elsevier

All outputs in CentAUR are protected by Intellectual Property Rights law, including copyright law. Copyright and IPR is retained by the creators or other copyright holders. Terms and conditions for use of this material are defined in the [End User Agreement](#).

www.reading.ac.uk/centaur

CentAUR

Central Archive at the University of Reading

Reading's research outputs online

The positive impacts of landscape fragmentation on the diversification of agricultural production in Zhejiang Province, China

Lefeng Qiu^{a*}, Jinxia Zhu^a, Yi Pan^a, Shaohua Wu^a, Yunxiao Dang^a, Baogen Xu^a, Hong Yang^b

^aInstitute of Land and Urban-rural Development, Zhejiang University of Finance and Economics, Hangzhou, 310018, China

^bDepartment of Geography and Environmental Science, University of Reading, Reading, RG6 6AB, UK

*Corresponding author.

Abstract

Agricultural land fragmentation has an important impact on ecosystem services, especially food production. However, the relationship between land fragmentation and production diversification remains controversial and requires further analysis. This study characterized the dynamics of land fragmentation and production diversification in Zhejiang Province, China, from 1995 to 2015 using remote sensing, landscape metrics, and a diversification assessment approach. The results showed that Zhejiang Province experienced increasing fragmentation of agricultural landscapes and profound diversification of agricultural production. Fragmentation had a significant negative effect on grain crop production, but it had a significant positive effect on production diversification. These findings showed that fragmentation is an important driver of the diversification of agriculture and contributes to increased dietary diversity in local households. Therefore, we believe that when addressing land fragmentation issues, both the positive and negative impacts of fragmentation in different local conditions and circumstances should be taken into account. Our findings will provide scientific support for land consolidation management and agricultural land resource protection.

Keywords: Land fragmentation; Production diversity; Land consolidation; Sustainability; Agricultural development; Zhejiang

31 **1. Introduction**

32 Agricultural land fragmentation caused by land use change and urbanization may have serious
33 impacts on ecosystem services, especially agricultural production (Lee et al., 2015; Costanza et al., 2017).
34 Fragmentation has negative impacts, such as a significant increase in the cost of agricultural production
35 (Liu et al., 2014; Lu et al., 2019) and a decrease in the technical and scale efficiency of agricultural
36 production (Tan et al., 2010). However, there are also ongoing debates about the benefits of fragmentation
37 to farmers under varying conditions. The positive effect is mainly reflected in the enrichment of the
38 internal planting structure of agriculture (Ntihinyurwa et al., 2019), the increase in the utilization of
39 labour resources (Tan et al., 2008), and the diversification of risks in relation to agricultural markets,
40 thereby increasing farmers' income (Lu et al., 2018). In this context, characterizing the relationship
41 between landscape pattern changes and agricultural production has become a critical step for evaluating
42 the comprehensive effect of fragmentation and developing subsequent land management policies.

43 China provides a typical case study for this effort. The Household Responsibility System (HRS)
44 implemented in China contributed to rapid rural development by increasing farmers' incomes and
45 eliminating rural poverty. However, its implementation also led to each household separately holding
46 numerous small, scattered plots of lands (Lu et al., 2018). In 2016, China had only 0.09 ha of cultivated
47 land per capita, far below the global average of 0.20 ha per capita (World Bank, 2016). Furthermore,
48 accelerating urbanization results in the physical fragmentation of agricultural land. The disorderly
49 establishment of a large number of urban construction sites led to scattered, isolated, and irregular
50 agricultural landscapes (Su et al., 2012; Lai et al., 2016). Zhang et al. (1997) found that fragmentation
51 wastes 5% of the effective area for farming in China and reduces land productivity by 15%.

52 At present, there are two main branches of research on the phenomenon of land fragmentation: land
53 ownership fragmentation and physical land fragmentation (Ntihinyurwa et al., 2019). Previous studies
54 frequently focused on the basic plots operated by farmers, assessing the ownership of plots, the size and
55 number of plots, the distance between plots, and the spatial distribution of plots from a socioeconomic
56 perspective (Wan and Cheng, 2001; Tan et al., 2010; Jia and Petrick, 2014; Lu et al., 2019). However,
57 from the perspective of landscape ecology, the composition and configuration of different landscape
58 patches will significantly affect ecosystem services (Coleman et al., 2017; Walz and Syrbe, 2018). The
59 spatial heterogeneity of the landscape characteristics of agricultural land in relation to agricultural

60 production should receive more attention (Lee and Huang, 2018). The relationship between landscape
61 fragmentation (LF) and agricultural production has yet to be studied. Since it is difficult to quantify land
62 fragmentation, the majority of studies use the number of plots owned by farmers or their average size to
63 measure fragmentation (Latruffe and Piet, 2014; Sibhatu et al., 2015), or they combine relevant
64 information to construct comprehensive indicators for reflecting fragmentation, such as the Januszewski
65 index or the Simpson index (Kawasaki, 2010; Ciaian et al., 2018). However, these indices ignore critical
66 spatial variables, such as the spatial isolation of farm fields and the shape of parcels. In addition, these
67 indices are commonly used for plot-level or farm-level studies and are difficult to apply in regional
68 fragmentation studies involving a larger spatial scale due to costly on-site investigations. Although the
69 information obtained from plot-scale research is more accurate, the observation of fragmentation patterns
70 throughout study areas in landscape-scale studies is more comprehensive (Mekki et al., 2018). Thus, it
71 has been proposed that the evaluation and application of landscape metrics is an efficient alternative for
72 quantifying fragmentation at the regional level (Cheng et al., 2015; Rosa et al., 2017; Lee and Huang,
73 2018).

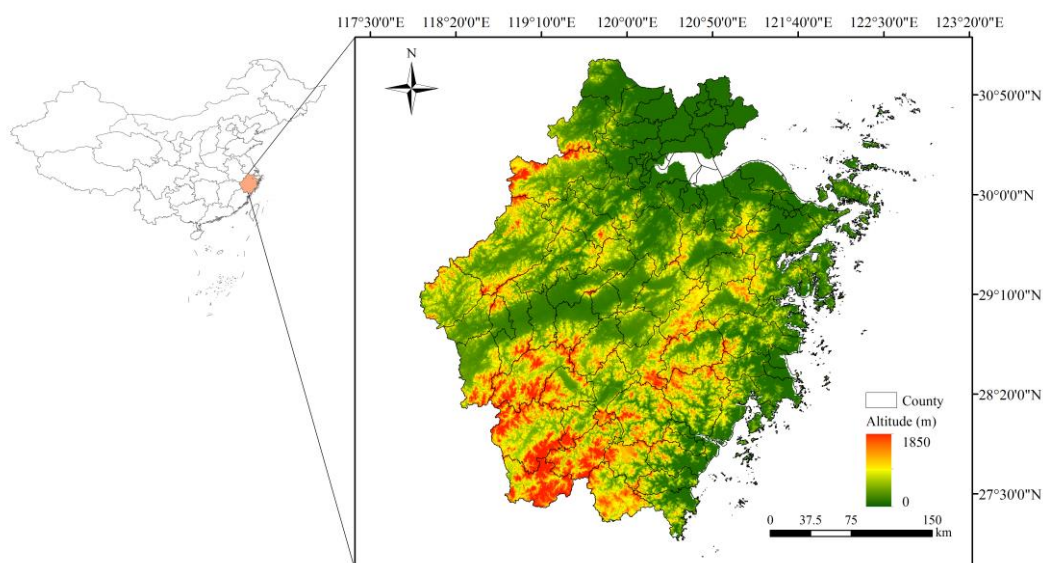
74 An important aspect of the effect of land fragmentation on agricultural production is the
75 diversification in the yields of different crops. Empirical literature mostly focuses on different factors
76 that influence farmers' diversification choices in agricultural production, such as farm household
77 characteristics, capital investments, crop price changes, technological updates, geographical location,
78 soil conditions, natural climate, and local agricultural policies (Sichoongwe et al., 2014; Loison, 2015;
79 McCord et al., 2015; Makate et al., 2016). Another important consideration is that the fragmentation of
80 regional agricultural land may potentially increase the diversity of agricultural products. Few studies
81 have revealed the relationship between land fragmentation and agricultural production diversification
82 (APD), despite a considerable number of studies analysing the determinants of APD (Ciaian et al., 2018).
83 Moreover, the few available studies find mixed evidence. For instance, Ciaian et al. (2018) and Mekki et
84 al. (2018) confirmed a positive effect of land fragmentation on production diversification at the level of
85 household farms in Albania and at the landscape level in Tunisia, but Sichoongwe et al. (2014) found a
86 statistically nonsignificant impact of land fragmentation on diversification at the level of smallholders in
87 Zambia. It is imperative to find more concrete evidence for specific areas at a more macro scale
88 (Sichoongwe et al., 2014).

89 To fill the knowledge gap, this study examines the impact of LF on APD using Zhejiang Province,
90 China, as a case study. A comprehensive approach combining remote sensing, landscape metrics and an
91 APD assessment method was developed to address the following three questions: (1) How did
92 agricultural landscape patterns change in response to urbanization in Zhejiang Province from 1995 to
93 2015? (2) How did agricultural production change in the context of rapid economic development? (3)
94 What is the relationship between land fragmentation and production diversification?

95 **2. Materials and methods**

96 *2.1. Study area*

97 Zhejiang Province (118°1'-122°26' E, 27°9'-31°11' N) is located in the southern part of the Yangtze
98 River Delta in China (Fig. 1). Zhejiang covers an area of approximately 105,500 km². The landscape is
99 characterized by mountainous topography. Hilly mountains account for 74.63% of the total area, plains
100 account for 20.32%, and water bodies account for 20.32%. With a population of 56.57 million in 2017,
101 Zhejiang Province is one of the provinces with the smallest per-capita cultivated land area in China (The
102 People's Government of Zhejiang Province, 2019). Since the 1980s, the commercialization of agriculture
103 in Zhejiang Province has developed rapidly, changing from single grain production to the cultivation of
104 higher-profit cash crops, such as tea, fruits, vegetables, and oil plants (Su et al., 2014). In the context of
105 rapid economic development and urbanization, Zhejiang Province is one of the richest and most
106 developed provinces in China (Zhao et al., 2019). The widespread transition from agricultural land to
107 construction land has intensified the fragmentation, irregularity, and isolation of agricultural patches
108 across the region (You, 2017). As a result, agricultural production is increasingly affected by land
109 fragmentation. The Zhejiang Provincial Government has proposed ecologically sustainable agriculture
110 as the development target of Zhejiang's future agriculture (Zhejiang Agricultural Department, 2016).
111 However, regarding the need to control land fragmentation, no comprehensive study on the relationship
112 between agricultural development and land fragmentation has previously been conducted.



113

114 Fig. 1 Location and topography of Zhejiang Province, China.

115 *2.2. Data source and processing*

116 Previous studies have shown that human factors affecting agricultural production generally include:
 117 the amount of labour, the area of sowing, irrigation, mechanical farming, and the usage of chemical
 118 fertilizers, pesticides, electricity, agricultural machinery, plastic film, etc. (Deng et al., 2017; Bai et al.,
 119 2018). In this study, we considered the following factors: the personnel engaged in crop farming (Pers),
 120 agricultural machinery usage (Mach), fertilizer usage (Fert), plastic mulch usage (Plas), pesticide usage
 121 (Pest), and landscape metrics. The data for these variables and the related total yields of agricultural
 122 products covered in this study were from 81 counties in Zhejiang Province from 1995 to 2015. The
 123 official data were collected from the statistical yearbooks published by government agencies
 124 (<http://tjj.zj.gov.cn/col/col1525563/index.html>).

125 The agricultural land ratio and landscape metrics were calculated from land use maps in 1995, 2005,
 126 and 2015 at a spatial resolution of 100 m × 100 m, supplied by the Data Center for Resources and
 127 Environmental Sciences (RESDC), Chinese Academy of Sciences (<http://www.resdc.cn>). Then, five
 128 categories of landscapes were generalized throughout the reclassification process (Qiu et al., 2019):
 129 agricultural land (cropland, fruit and tea orchards), built-up land (cities, towns, and rural area), forest
 130 (broadleaved forests, shrubland, and mixed forests), vacant land (bare land and rocky areas), and water
 131 bodies.

132 *2.3. Measurement of land fragmentation*

133 Landscape metrics have been widely used to analyse changes in landscape patterns. Four landscape

134 metrics were selected in this study to assess fragmentation using Fragstats 4.2 software (McGarigal et
 135 al., 2012) (Table 1). Changes in the area of agricultural land directly affect agricultural production.
 136 Therefore, agricultural production can be reflected by agricultural land percentages (PLAND) (Lee et al.,
 137 2015). In addition, relatively large agricultural land size (mean patch size, MPS), more aggregated
 138 distributions (aggregation index, AI) and more regular shapes of the agricultural land (landscape shape
 139 index, LSI) increase the efficiency of actual agricultural practice (Deng et al., 2011; Su and Xiao, 2013).
 140 When the landscape is fragmented due to human activities, the number of patches increases and the
 141 average size of each patch decreases, resulting in more complex edges. Meanwhile, the distribution of
 142 agricultural land becomes scattered. By using these indicators, we can evaluate the level of fragmentation
 143 in each county and the entire province during the 20-year research period.

144 Table 1 Landscape metrics for characterizing agricultural landscape pattern

Metrics	Abbreviation	Description	Range
Percentage of landscape	PLAND	PLAND equals the percentage of the landscape composed of the corresponding patch type	$0 < \text{PLAND} \leq 100$
Mean patch size	MPS	MPS equals the average area of all the agricultural land patches	$\text{MPS} > 0$
Aggregation index	AI	AI equals the number of like adjacencies divided by the maximum possible number of like adjacencies	$0 \leq \text{AI} \leq 100$
Landscape shape index	LSI	LSI equals the total length of the edge divided by the minimum length of the class edge possible for a maximally aggregated class	$\text{LSI} \geq 1$

145 Abbreviations: percentage of agricultural landscape (PLAND), mean patch size (MPS), aggregation
 146 index (AI), and landscape shape index (LSI).

147 2.4. Measurement of production diversification

148 For the past two decades, the number of major crop species in Zhejiang has remained stable, but the
 149 proportion of different crops in the total output of agricultural products has been constantly changing due
 150 to the transformation of crop farming from a single grain crop to diversified agricultural products
 151 throughout the country (Su et al., 2014). Simple counting of crop species or formulas based on changes
 152 in the number of crop species, such as the Margalef species richness index (Sibhatu et al., 2015),
 153 Simpson's index (Ciaian et al., 2018), and the Januszewski index (Looga et al., 2018), failed to accurately

154 reflect the trend in the diversification of agricultural production in the study area. Thus, unlike previous
 155 studies on production diversity, we believe that using the relative proportion of different crop yields to
 156 measure production diversity is more realistic than using the number of crop species at the regional scale.
 157 In this study, the production diversity was measured by calculating the agricultural structure coefficient,
 158 i.e., the ratio of cash crop output to grain output (CGR) for each county in Zhejiang. This is a simple and
 159 unweighted quantitative measure commonly used in China's agricultural economic literature and as an
 160 indicator to describe agricultural land use changes and assess planting structure diversity (Ning and Liu,
 161 2013; Li et al., 2018). To test the robustness of this approach, we used Simpson's index to examine
 162 whether this influences the results significantly. Simpson's index is often used in the biodiversity
 163 literature, and it indicates the cultivated area or yield of different crop species in a region (Huang et al.,
 164 2019; Nicod et al., 2019).

165 The ratio of the cash crop output to grain output can be expressed as follows:

$$166 \quad CGR = V_{cashcrop} / V_{grain} \quad (1)$$

167 where $V_{cashcrop}$ and V_{grain} are the output yields of grain and cash crop cultivation, respectively. As the value
 168 of CGR increases, the proportion of traditional grain cultivation shrinks, that of cash crop cultivation
 169 increases, and agricultural production structure becomes more diverse. Based on the cash crops actually
 170 planted in Zhejiang, Eq. (1) can be further expressed as:

$$171 \quad CGR = (V_{oil} + V_{vegetable} + V_{tea} + V_{fruit}) / V_{grain} \quad (2)$$

172 where V_{oil} , $V_{vegetable}$, V_{tea} , and V_{fruit} refer to the output yields of oil plants, vegetables, tea, and fruits,
 173 respectively. Simpson's index can be expressed as:

$$174 \quad S = 1 - \sum_{i=1}^N V_i^2 / \left(\sum_{i=1}^N V_i \right)^2 \quad (3)$$

175 where y_i is the output yield of crop i that a county produces, and N is the number of crops. The value of
 176 the index varies between zero and one, with a larger value indicating more diversity.

177 2.5. Data analysis

178 Considering the uncertainty of the effects of LF on agricultural production, we first explored the
 179 relationship between agricultural production indicators and landscape metrics using Spearman's
 180 correlation analysis. Next, we used landscape metrics together with other control variables in regression
 181 models to further investigate the causality of grain crop production (GCP) and APD.

182 The regression model used is as shown below:

$$183 \quad y_{ij} = \alpha + \beta x_{ij} + \gamma z_{ij} + \varepsilon_{ij} \quad (3)$$

184 where y_{ij} denotes the GCP or APD in county i and year j , α is the intercept, x_{ij} denotes the fragmentation
185 metrics in county i and year j , z_{ij} is the control variables in county i and year j , and β and γ are the
186 regression coefficients of x_{ij} and z_{ij} , respectively. The residual ε_{ij} is an unobserved scalar random error.
187 We tested different functional forms of Eq. (3) for normality of the residual (Kolmogorov-Smirnov test)
188 and goodness of fit (R-squared) to select the most appropriate one. Using logarithms for the control
189 variables and for the fragmentation metric of MPS (among other metrics: PLAND and AI lie between 0
190 and 100, and LSI is a ratio greater than or equal to 1, Table 1), we selected the following regression
191 model:

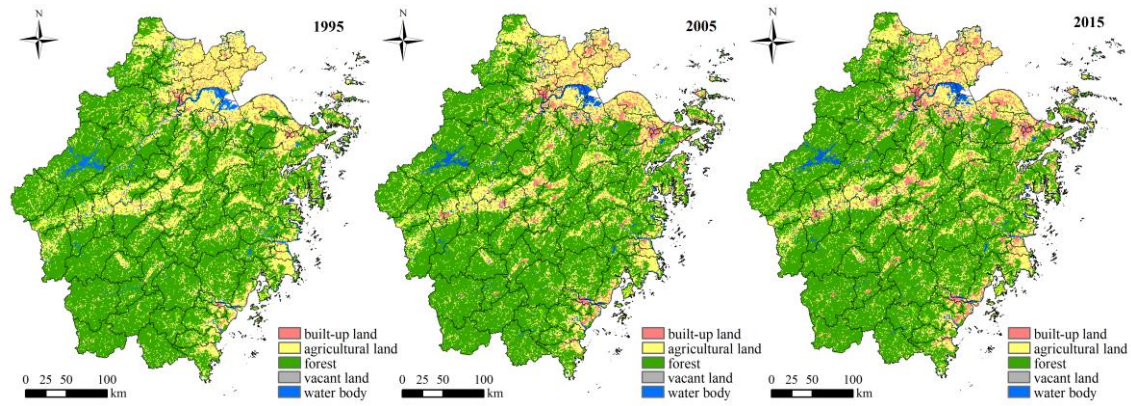
$$192 \quad y_{ij} = \alpha + \beta x_{ij} + \gamma_1 \ln(Pers_{ij}) + \gamma_2 \ln(Mach_{ij}) + \gamma_3 \ln(Fert_{ij}) + \gamma_4 \ln(Plas_{ij}) + \gamma_5 \ln(Pest_{ij}) + \varepsilon_{ij} \quad (4)$$

193 where x_{ij} refers to PLAND, ln (MPS), AI, and LSI, and $\gamma_1, \dots, \gamma_5$ are regression coefficients.

194 **3. Results**

195 *3.1. Changes in the agricultural landscape*

196 The landscape changes in Zhejiang are mainly triggered by urbanization. Due to rapid economic
197 and urban development across the province, the landscape has changed dramatically, mainly transforming
198 from agricultural land to built-up land. Approximately 11.6% of the agricultural land in Zhejiang was
199 changed to other land use types between 1995 and 2015 (Fig. 2). The agricultural landscape metrics in
200 Zhejiang were summarized as the average values of the counties (or districts) and are shown in Table 2.
201 Nine urban districts with no agricultural land were excluded from the analysis. Due to the loss of
202 agricultural land over the past few decades, PLAND has generally declined in all counties, especially in
203 the more developed northeastern region. Meanwhile, an increasingly fragmented composition and a
204 scattered distribution of agricultural land were observed, as evidenced by the decrease in MPS and AI in
205 Zhejiang during the past two decades. The decline in MPS indicates that the patch size of agricultural
206 land has decreased, while the decline in AI indicates that agricultural lands have become more isolated.
207 The mean LSI of all the counties increased from 1995 to 2015, indicating that the shape of the agricultural
208 land patches became more irregular.



209

210 Fig. 2 Landscape patterns in Zhejiang Province, China, between 1995 and 2015.

211 Table 2 Landscape metrics of the agricultural land in Zhejiang Province, China, between 1995 and

212 2015.

Metrics	1995		2005		2015	
	Mean	Range	Mean	Range	Mean	Range
PLAND	35.55	2.71-87.63	24.49	1.41-63.55	21.76	1.23-70.15
MPS	24.54	0.51-79.85	13.57	0.25-53.83	11.86	0.08-60.96
AI	50.27	23.1-97.26	40.41	18.93-75.71	38.21	19.44-78.74
LSI	15.33	10.39-20.32	16.72	10.8-21.48	18.22	10.28-21.28

213 Abbreviations: percentage of agricultural landscape (PLAND), mean patch size (MPS), aggregation
 214 index (AI), and landscape shape index (LSI).

215 *3.2. Changes in agricultural production*

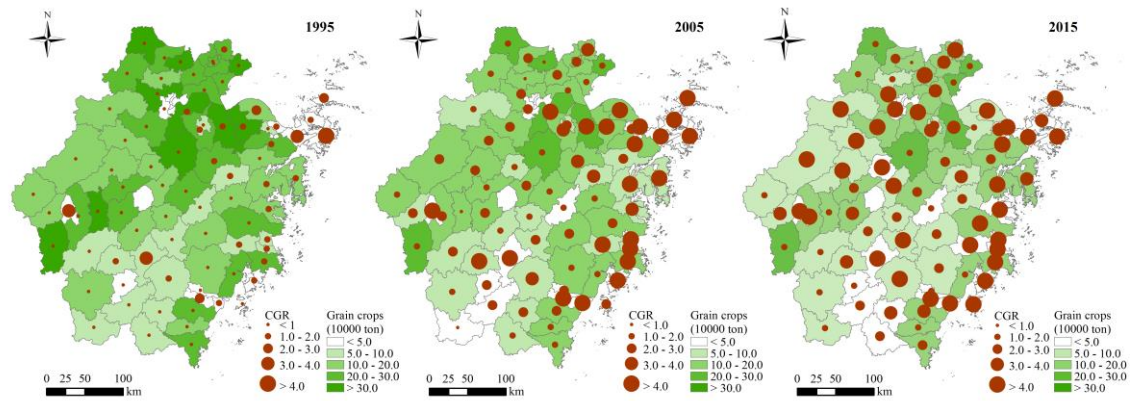
216 The production of cash crops, such as vegetables, tea, and fruits, continuously increased, while the
 217 production of grain crops and oil plants decreased between 1995 and 2015 (Table 3). Specifically, fruit
 218 production showed a dramatic growth of 244.53%. Vegetable and tea production significantly increased
 219 by 89.33% and 61.54%, respectively. Grain crop production showed a net decrease of 47.99%. This
 220 suggested that the agricultural planting structure in Zhejiang Province shifted from traditional grain crop
 221 cultivation to more diverse crops, such as vegetables, fruits, and tea. In the past two decades, the value
 222 of CGR has grown by 348.60%, indicating that the agricultural production structure has become more
 223 diverse. The continued increase in the value of Simpson's index also reflects the diversification trend,
 224 demonstrating that using CGR to estimate diversity provides robust results in this study.

225

226 Table 3 Descriptive statistics of the agricultural production variables and agricultural products in
 227 Zhejiang Province, China, between 1995 and 2015.

Variables	Unit	<i>n</i>	Mean		
			1995	2005	2015
Grain crops	10000 <i>Tons</i>	81	17.67	10.86	9.19
Oil plants	10000 <i>Tons</i>	81	0.62	0.60	0.47
Vegetables	10000 <i>Tons</i>	81	11.62	21.66	22.00
Tea	10000 <i>Tons</i>	81	0.13	0.18	0.21
Fruits	10000 <i>Tons</i>	81	2.65	6.58	9.13
Personnel engaged in crop farming	10000 <i>People</i>	81	14.15	9.59	6.07
Power of agricultural machinery	10000 <i>kw</i>	81	20.25	23.12	28.90
Fertilizer	10000 <i>Tons</i>	81	5.75	4.72	4.55
Plastic mulch	10000 <i>Tons</i>	81	0.03	0.05	0.08
Pesticides	10000 <i>Tons</i>	81	0.07	0.08	0.07
CGR		81	1.07	3.43	4.80
Simpson's index		81	0.54	0.56	0.58

228 Fig. 3 shows the spatial patterns of grain production and CGR for Zhejiang in 1995, 2005, and 2015.
 229 In general, CGR growth was spatially distributed across the province. In this paper, we set the CGR value
 230 equal to 3; this was the threshold for diversified agricultural production using the Jenks natural breaks
 231 classification method (Liu et al., 2019). In 1995, the CGR values of only four scattered counties were
 232 greater than 3, while the CGR values of the other counties were generally low, indicating the homogeneity
 233 of the province's agricultural production structure. By 2005, the number of counties with CGR values
 234 greater than 3 reached 28, most of which were spatially located in the eastern coastal areas. The CGR
 235 values of some counties in the western region were significantly improved in the following decade. By
 236 2015, more than half of the counties had a CGR value greater than 3, representing a significant
 237 diversification of the agricultural production structure in Zhejiang Province during the past two decades.
 238 At the same time, grain production showed a continuous downward trend corresponding to the spatial
 239 growth of CGR.



240

241 Fig. 3 Distribution of grain production and CGR at the county level in Zhejiang Province, China, between
 242 1995 and 2015.

243 *3.3. Relationship between land fragmentation and production diversification*

244 Significant correlations were identified between the landscape metrics and agricultural production
 245 indicators (Table 4). Specifically, GCP was positively correlated with PLAND, MPS, and AI but
 246 negatively correlated with LSI. The opposite relationship was found between CGR and the landscape
 247 metrics. As indicated by the estimation results of the regression models (Table 5), LF had a significant
 248 influence on agricultural production. In the regression model with a dependent variable of GCP, the
 249 highly significant positive coefficients of 0.02, 0.187, and 0.022 for PLAND, ln (MPS), and AI,
 250 respectively, and the highly significant negative coefficient of -0.085 for LSI indicated that high
 251 fragmentation was associated with a significant reduction in GCP. In addition, in the regression model
 252 with a dependent variable of CGR, the highly significant negative coefficients of -0.065, -0.52, and -
 253 0.074 for PLAND, ln (MPS), and AI, respectively, and the highly significant positive coefficient of 0.344
 254 for LSI indicated that high fragmentation was associated with a high diversification of agricultural
 255 production. These findings demonstrate that LF has a negative impact on GCP but has a significant
 256 positive impact on APD.

257 Table 4 Spearman's correlation analysis between landscape metrics and agricultural production
 258 indicators.

	PLAND	MPS	AI	LSI
GCP	0.837**	0.791**	0.820**	-0.693**
CGR	-0.417**	-0.356**	-0.409**	0.501**

259 Notes: **Significant at 1% and *Significant at 5%.

260 Abbreviations: percentage of agricultural landscape (PLAND), mean patch size (MPS), aggregation
 261 index (AI), landscape shape index (LSI), grain crop production (GCP), and the ratio of cash crop output
 262 to grain output (CGR).

263 Table 5 Regression results between the landscape metrics and agricultural production by controlling
 264 variables

Model 1	Model 2	Model 3	Model 4
Dependent variable: GCP			
ln (Pers)	0.236**	ln (Pers)	0.242**
ln (Mach)	-0.070	ln (Mach)	-0.045
ln (Fert)	0.465**	ln (Fert)	0.518**
ln (Plas)	-0.013	ln (Plas)	-0.049
ln (Pest)	0.118*	ln (Pest)	0.146*
PLAND	0.020**	ln (MPS)	0.187**
Constant	1.063**	AI	0.022**
R ²	0.794	LSI	-0.085**
		Constant	2.966**
		R ²	0.753
Dependent variable: CGR			
ln (Pers)	-0.643*	ln (Pers)	-0.681*
ln (Mach)	1.205**	ln (Mach)	1.099**
ln (Fert)	-1.118**	ln (Fert)	-1.307**
ln (Plas)	0.730**	ln (Plas)	0.851**
ln (Pest)	0.262	ln (Plas)	0.723**
PLAND	-0.065**	ln (Plas)	0.665**
Constant	7.276**	ln (Pest)	0.187
R ²	0.270	PLAND	-0.520*
		AI	-0.074**
		LSI	0.344**
		Constant	-0.266
		R ²	0.246

265 Notes: ** Significant at 1% and * Significant at 5%.

266 Abbreviations: the personnel engaged in crop farming (Pers), agricultural machinery usage (Mach),
 267 fertilizer usage (Fert), plastic mulch usage (Plas), pesticide usage (Pest), percentage of agricultural
 268 landscape (PLAND), mean patch size (MPS), aggregation index (AI), landscape shape index (LSI), grain
 269 crop production (GCP), and the ratio of cash crop output to grain output (CGR).

270 **4. Discussion**

271 *4.1. The impacts of land fragmentation on agricultural production*

272 Generally, land fragmentation is considered a major threat to efficient agricultural production
273 systems because, with continued shrinking, fragmented agricultural plots may be hard to cultivate
274 economically. The negative relationship between fragmentation and GCP has been demonstrated
275 throughout the world. Wan and Cheng (2001) reported that the fragmentation of cultivated land is one of
276 the major factors contributing to the decreased benefits of agricultural production in China. Rahman and
277 Rahman (2009) found that land fragmentation had a significant detrimental effect on the productivity and
278 efficiency of rice production in Bangladesh. They estimated that a 1% increase in land fragmentation
279 reduced rice output by 0.05% and efficiency by 0.03%. Latruffe and Piet (2014) identified a significant
280 negative impact of land fragmentation on crop yields, leading to increased production costs and reduced
281 revenues and profits of farms in France. Our study in Zhejiang Province confirms the negative aspects
282 of land fragmentation, that is, land fragmentation is a negative factor in food security because it reduces
283 the efficiency of food crop production.

284 On the other hand, it has been argued that land fragmentation has a positive impact on food security
285 improvement by matching soil types with appropriate food crops (Van Hung et al., 2007; Demetriou et
286 al., 2013), reducing climate hazards and pest risks (Sklenicka and Salek, 2008; Ciaian et al., 2018), and
287 leading to production diversity and dietary diversity (Sikor et al., 2009; Ntihinyurwa et al., 2019). In
288 addition, there is a view that land consolidation practices that reduce fragmentation by relocating and
289 enlarging plots will have a negative impact on agricultural ecosystem services such as biodiversity
290 (Tiemann et al., 2015; Schulte et al., 2017), culture and recreation (Mitchell et al., 2015; Qiu et al., 2019).
291 Our findings support these arguments, as illustrated by the positive relationship between CGR and
292 landscape fragmentation metrics at the provincial level in China. Our findings show that the diversity or
293 heterogeneity of the land and the different soil qualities and production potential caused by fragmentation
294 have effects on the agricultural system. The greater the diversity of growing conditions, the greater the
295 diversity of crops and diets, and the higher the sustainability of food production, the higher the food
296 security. This is consistent with the Sustainable Development Goals from the 2030 Agenda for
297 Sustainable Development of ending hunger, achieving food security, and promoting sustainable
298 agriculture (Goal 1), and sustainable use of land resources and conservation of biodiversity (Goal 15)

299 (Inter-Agency and Expert Group on SDG Indicators, 2017). The achievement of these goals requires the
300 planning and implementation of sustainable and ecological agriculture that needs to be adapted to local
301 conditions, the planting of crops with different adaptability on land with different resource endowments
302 and growing conditions to promote the biodiversity of crops and livestock, an increase in the diversity
303 and characteristics of agricultural products, and the support of sustainable agricultural production (Lee
304 et al., 2015; Fagerholm et al., 2016; Burchfield and Poterie, 2018). This is preferential over market-
305 oriented large-scale industrial agricultural production, which usually leads to a simplification of
306 agricultural production structure, accelerates the loss of agro-biodiversity (Šálek et al., 2018), reduces
307 nutritional levels due to the risk of pests, disease invasion, and environmental pollution (Li et al., 2020),
308 and ultimately threatens human health (Liu et al., 2020). Ecological agriculture requires a deep and
309 comprehensive understanding of regional characteristics, the positioning of agricultural development,
310 land use, and the dual impacts of land fragmentation discussed above.

311 The reason for the difference between the two above-mentioned viewpoints is that most of the
312 previous studies did not consider the different forms of land fragmentation, the geographical
313 characteristics of different agricultural areas, the transformation of sustainable agriculture, or all the
314 various aspects of food security. Those studies focus only on the impact of land fragmentation on the
315 efficiency of large-scale agricultural production and believe that land fragmentation threatens the total
316 amount of food but ignores food diversity and sustainability, which are important aspects of food security.
317 Therefore, it should be recognized that not all land fragmentation is harmful to agricultural production.
318 The strategy and choices for dealing with land fragmentation should be based on a comprehensive
319 assessment of the local ecological, social, economic, and political contexts and the positioning of
320 agricultural development.

321 *4.2. Implications for land management*

322 To alleviate the problem of continuously declining in grain production capacity caused by the loss
323 of cultivated land, since the mid-1990s, the central government of China has implemented a series of
324 policies and measures to protect land resources and promote land consolidation (Yang, 2016). The aim
325 of these policies is to increase cropland area, reduce land fragmentation, mitigate land pollution, and
326 promote agricultural productivity (Song and Pijanowski, 2014; Du et al., 2018). Modern land
327 consolidation projects can usually achieve the goal of reducing the number of scattered plots, regulating

328 the shape of plots, and increasing the size of large-scale farms in the context of commercial and
329 mechanized agriculture in China's main grain production bases. However, previous land consolidation
330 management overemphasized the negative impact of fragmentation on productivity and food quantity but
331 ignored the positive impact of fragmentation on food diversity and sustainability. As found in the
332 Zhejiang case study above, it is not necessary to address all the land fragmentation issues in China's rural
333 hilly areas dominated by ecologically sustainable agriculture. Land consolidation should be primarily
334 implemented in more homogenous regions with less variability in elevation, slope, soil quality, and agro-
335 ecological conditions to achieve the goal of increasing the amount of food. Other regions with greater
336 heterogeneity can maintain a moderate level of fragmentation or develop more local, context-specific
337 land consolidation approaches to take advantage of the positive impacts of fragmentation on production
338 diversity. Since the balance between yield and diversity inevitably involves trade-offs, trade-off analyses,
339 including threshold analysis, multi-objective analysis, scenario analysis, and model simulation, are
340 becoming increasingly necessary (Sherrouse et al., 2017; Yang et al., 2018). Quantifying these trade-offs
341 or synergies improves the management and protection of agricultural land by revealing the optimal
342 allocation of agricultural land services and functions (Deng et al., 2017). The results of these studies will
343 provide scientific support for achieving optimal land fragmentation levels and planning local, specific
344 land consolidation activities.

345 *4.3. Limitations and future research*

346 The current research still has some limitations that should be considered in the future. First, more
347 potential influencing factors should be evaluated, including the soil physical, chemical, and biophysical
348 characteristics of agricultural land, natural resources, and regional agricultural policies. In the future, by
349 supplementing and analysing these variables, it should be possible to provide a more complete and
350 comprehensive understanding of the dynamic process of production diversification. Second, it should
351 also be noted that APD does not necessarily mean diversification in the yields of different crops; rather,
352 it can imply the number of crops in a farm or land block or the diversity of the crops. Third, the
353 relationship between land fragmentation and diversification was analysed at the regional landscape scale.
354 These relationships should be further described at the field and farm scales to deepen our knowledge of
355 the decision-making process by farmers related to the diversification of production. Finally, this study
356 has yet to determine the extent and threshold of the impact of land fragmentation on agricultural

357 diversification.

358 **5. Conclusions**

359 In this paper, we examined agricultural land fragmentation and its implications for production
360 diversification using Zhejiang Province, China, as a case study. Zhejiang represents a typical case for
361 studying land fragmentation and its impacts on agricultural production. The conflicts between the
362 population, land resources and urbanization have made Zhejiang one of the most fragmented agricultural
363 landscapes in China. This paper contributes to the quantitative measurement and presentation of the
364 effects of land fragmentation on production diversification by using landscape metrics and the CGR index.
365 Based on the multi-source data from 1995, 2005 and 2015, we used agricultural labourers, machinery
366 usage, fertilizer usage, plastic mulch usage, pesticide usage, and the landscape metrics of PLAND, MPS,
367 AI, and LSI as the independent variables to explain production diversification. Then, the explicit
368 relationship between fragmentation and diversification was extracted from the results of the model
369 analysis.

370 The results showed that the agricultural landscape pattern has been increasingly fragmented and
371 agricultural production has been increasingly diverse over the past two decades. We found that land
372 fragmentation was significantly negatively correlated with GCP but was significantly positively
373 correlated with APD. This finding indicated that land fragmentation is an important driver of agricultural
374 diversification at the provincial level in China. We further discussed the positive impact that land
375 fragmentation has on food security improvement from the perspective of food diversity and sustainability.
376 Therefore, the strategies for dealing with land fragmentation should be based on a comprehensive
377 assessment of the local ecological, social, economic, and political contexts and the positioning of
378 agricultural development. The lessons learned from Zhejiang Province will provide scientific support for
379 land consolidation management and agricultural land resource protection.

380

381 **Conflicts of interest**

382 The authors declare no conflict of interest.

383

384 **Acknowledgments**

385 This research was financially supported by Natural Science Foundation of Zhejiang Province (No.
386 LY19D010002). We gratefully acknowledge the Data Center for Resources and Environmental Sciences,
387 Chinese Academy of Sciences (RESDC) (<http://www.resdc.cn>) for the supply of source data set.

388 **References**

- 389 Bai, Y., Deng, X., Jiang, S., Zhao, Z., Miao, Y., 2018. Relationship between climate change and low-
390 carbon agricultural production: A case study in Hebei Province, China. *Ecol. Indic.* 105, 438-447.
- 391 Burchfield, E. K., Poterie, A. T. d. l., 2018. Determinants of crop diversification in rice-dominated Sri
392 Lankan agricultural systems. *J. Rural Stud.* 61, 206-215.
- 393 Cheng, L., Xia, N., Jiang, P., Zhong, L., Pian, Y., Duan, Y., Huang, Q., Li, M., 2015. Analysis of farmland
394 fragmentation in China Modernization Demonstration Zone since " Reform and Openness": A case
395 study of South Jiangsu Province. *Sci. Rep.* 5, 11797.
- 396 Ciaian, P., Guri, F., Rajcaniova, M., Drabik, D., Paloma, S. G. y., 2018. Land fragmentation and
397 production diversification: A case study from rural Albania. *Land Use Pol.* 76, 589-599.
- 398 Coleman, K., Muhammed, S. E., Milne, A. E., Todman, L. C., Dailey, A. G., Glendining, M. J., Whitmore,
399 A. P., 2017. The landscape model: A model for exploring trade-offs between agricultural production
400 and the environment. *Sci. Total Environ.* 609(Supplement C), 1483-1499.
- 401 Costanza, R., de Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., Farber, S., Grasso, M.,
402 2017. Twenty years of ecosystem services: How far have we come and how far do we still need to
403 go? *Ecosyst. Serv.* 28, 1-16.
- 404 Demetriou, D., Stillwell, J., See, L., 2013. A new methodology for measuring land fragmentation.
405 *Comput. Environ. Urban Syst.* 39, 71-80.
- 406 Deng, J. S., Qiu, L. F., Wang, K., Yang, H., Shi, Y. Y., 2011. An integrated analysis of urbanization-
407 triggered cropland loss trajectory and implications for sustainable land management. *Cities* 28(2),
408 127-137.
- 409 Deng, X., Gibson, J., Wang, P., 2017. Management of trade-offs between cultivated land conversions and
410 land productivity in Shandong Province. *J. Clean Prod.* 142, 767-774.
- 411 Deng, X., Gibson, J., Wang, P., 2017. Relationship between landscape diversity and crop production: a
412 case study in the Hebei Province of China based on multi-source data integration. *J. Clean Prod.*
413 142, 985-992.
- 414 Du, X., Zhang, X., Jin, X., 2018. Assessing the effectiveness of land consolidation for improving
415 agricultural productivity in China. *Land Use Pol.* 70, 360-367.
- 416 Fagerholm, N., Oteros-Rozas, E., Raymond, C. M., Torralba, M., Moreno, G., Plieninger, T., 2016.

417 Assessing linkages between ecosystem services, land-use and well-being in an agroforestry
418 landscape using public participation GIS. *Appl. Geogr.* 74, 30-46.

419 Huang, C., Zhou, Z., Peng, C., Teng, M., Wang, P., 2019. How is biodiversity changing in response to
420 ecological restoration in terrestrial ecosystems? A meta-analysis in China. *Sci. Total Environ.* 650,
421 1-9.

422 Inter-Agency and Expert Group on SDG Indicators, 2017. Global indicator framework for the
423 Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development. the
424 United Nations Statistical Commission, New York.

425 Jia, L., Petrick, M., 2014. How does land fragmentation affect off-farm labor supply: panel data evidence
426 from China. *Agric. Econ.* 45(3), 369-380.

427 Kawasaki, K., 2010. The costs and benefits of land fragmentation of rice farms in Japan. *Aust. J. Agr.*
428 *Resour. Econ.* 54(4), 509-526.

429 Lai, L., Huang, X., Yang, H., Chuai, X., Zhang, M., Zhong, T., Chen, Z., Chen, Y., Wang, X., Thompson,
430 J. R., 2016. Carbon emissions from land-use change and management in China between 1990 and
431 2010. *Sci. Adv.* 2(11), e1601063.

432 Latruffe, L., Piet, L., 2014. Does land fragmentation affect farm performance? A case study from Brittany,
433 France. *Agric. Syst.* 129, 68-80.

434 Lee, Y.-C., Ahern, J., Yeh, C.-T., 2015. Ecosystem services in peri-urban landscapes: The effects of
435 agricultural landscape change on ecosystem services in Taiwan's western coastal plain. *Landsc.*
436 *Urban Plan.* 139, 137-148.

437 Lee, Y. C., Huang, S. L., 2018. Spatial emergy analysis of agricultural landscape change: Does
438 fragmentation matter? *Ecol. Indic.* 93, 975-985.

439 Li, E., Xu, Y., Yong, Y., Wei, L., 2018. Agricultural structure adjustment and rural transformation
440 development in China, *Progress in Geography* 37(05), 698-709.

441 Li, H., Yang, Z., Dai, M., Diao, X., Dai, S., Fang, T., Dong, X., 2020. Input of Cd from agriculture
442 phosphate fertilizer application in China during 2006–2016. *Sci. Total Environ.* 698, 134149.

443 Liu, Y., Huang, X., Yang, H., Zhong, T., 2014. Environmental effects of land-use/cover change caused
444 by urbanization and policies in Southwest China Karst area – A case study of Guiyang. *Habitat Int.*
445 44, 339-348.

446 Liu, Y., Li, T., Zhao, W., Wang, S., Fu, B., 2019. Landscape functional zoning at a county level based on
447 ecosystem services bundle: Methods comparison and management indication. *J. Environ. Manage.*
448 249, 109315.

449 Liu, Y., Sun, D., Wang, H., Wang, X., Yu, G., Zhao, X., 2020. An evaluation of China's agricultural green
450 production: 1978–2017. *J. Clean Prod.* 243, 118483.

451 Loison, S. A., 2015. Rural Livelihood Diversification in Sub-Saharan Africa: A Literature Review AU -
452 Alogo Loison, Sarah. *J. Dev. Stud.* 51(9), 1125-1138.

453 Looga, J., Jürgenson, E., Sikk, K., Matveev, E., Maasikamäe, S., 2018. Land fragmentation and other
454 determinants of agricultural farm productivity: The case of Estonia. *Land Use Pol.* 79, 285-292.

455 Lu, H., Xie, H., He, Y., Wu, Z., Zhang, X., 2018. Assessing the impacts of land fragmentation and plot
456 size on yields and costs: A translog production model and cost function approach. *Agric. Syst.* 161,
457 81-88.

458 Lu, H., Xie, H., Yao, G., 2019. Impact of land fragmentation on marginal productivity of agricultural
459 labor and non-agricultural labor supply: A case study of Jiangsu, China. *Habitat Int.* 83, 65-72.

460 Makate, C., Wang, R., Makate, M., Mango, N., 2016. Crop diversification and livelihoods of smallholder
461 farmers in Zimbabwe: adaptive management for environmental change. *SpringerPlus* 5(1), 1135-
462 1135.

463 McCord, P. F., Cox, M., Schmitt-Harsh, M., Evans, T., 2015. Crop diversification as a smallholder
464 livelihood strategy within semi-arid agricultural systems near Mount Kenya. *Land Use Pol.* 42, 738-
465 750.

466 McGarigal, K., Cushman, S. A., Ene, E., 2012. FRAGSTATS v4: Spatial Pattern Analysis Program for
467 Categorical and Continuous Maps. the University of Massachusetts, Amherst.

468 Mekki, I., Bailly, J. S., Jacob, F., Chebbi, H., Ajmi, T., Blanca, Y., Zairi, A., Biarnès, A., 2018. Impact of
469 farmland fragmentation on rainfed crop allocation in Mediterranean landscapes: A case study of the
470 Lebna watershed in Cap Bon, Tunisia. *Land Use Pol.* 75, 772-783.

471 Mitchell, M.G.E., Suarez-Castro, A.F., Martinez-Harms, M., Maron, M., McAlpine, C., Gaston, K.J.,
472 Johansen, K., Rhodes, J.R., 2015. Reframing landscape fragmentation's effects on ecosystem
473 services. *Trends Ecol. Evol.* 30(4), 190-198.

474 Nicod, C., Leys, B., Ferrez, Y., Manneville, V., Mouly, A., Greffier, B., Hennequin, C., Bouton, Y.,

475 Prévost-Bouré, N.C., Gillet, F., 2019. Towards the assessment of biodiversity and management
476 practices in mountain pastures using diagnostic species? *Ecol. Indic.* 107, 105584.

477 Ning, A., Liu, Y., 2013. The efficiency of agricultural grain production under urbanization. *Resources*
478 *Science* 35(6), 1174-1183.

479 Ntihinyurwa, P. D., de Vries, W. T., Chigbu, U. E., Dukwiyimpuhwe, P. A., 2019. The positive impacts
480 of farm land fragmentation in Rwanda. *Land Use Pol.* 81, 565-581.

481 Qiu, L., Pan, Y., Zhu, J., Amable, G. S., Xu, B., 2019. Integrated analysis of urbanization-triggered land
482 use change trajectory and implications for ecological land management: A case study in Fuyang,
483 China. *Sci. Total Environ.* 660, 209-217.

484 Rahman, S., Rahman, M., 2009. Impact of land fragmentation and resource ownership on productivity
485 and efficiency: The case of rice producers in Bangladesh. *Land Use Pol.* 26(1), 95-103.

486 Rosa, I. M. D., Gabriel, C., Carreiras, J. M. B., 2017. Spatial and temporal dimensions of landscape
487 fragmentation across the Brazilian Amazon. *Reg. Envir. Chang.* 17(6), 1687-1699.

488 Šálek, M., Hula, V., Kipson, M., Daňková, R., Niedobová, J., Gamero, A., 2018. Bringing diversity back
489 to agriculture: Smaller fields and non-crop elements enhance biodiversity in intensively managed
490 arable farmlands. *Ecol. Indic.* 90, 65-73.

491 Schulte, L. A., Niemi, J., Helmers, M. J., Liebman, M., Arbuckle, J. G., James, D. E., Kolka, R. K.,
492 O'Neal, M. E., Tomer, M. D., Tyndall, J. C., Asbjornsen, H., Drobney, P., Neal, J., Van Ryswyk, G.,
493 Witte, C., 2017. Prairie strips improve biodiversity and the delivery of multiple ecosystem services
494 from corn–soybean croplands. *Proc. Natl. Acad. Sci. U. S. A.* 114(42), 11247-11252.

495 Sherrouse, B.C., Semmens, D.J., Ancona, Z.H., Brunner, N.M., 2017. Analyzing land-use change
496 scenarios for trade-offs among cultural ecosystem services in the Southern Rocky Mountains.
497 *Ecosyst. Serv.* 26(Part B), 431-444.

498 Sibhatu, K. T., Krishna, V. V., Qaim, M., 2015. Production diversity and dietary diversity in smallholder
499 farm households. *Proc. Natl. Acad. Sci. U. S. A.* 112(34), 10657-10662.

500 Sichoongwe, K., Mapemba, L., Tembo, G., Ng'ong'ola, D., 2014. The Determinants and Extent of Crop
501 Diversification Among Smallholder Farmers: A Case Study of Southern Province Zambia. MaSSP
502 Working Paper, Washington, D.C.

503 Sikor, T., Müller, D., Stahl, J., 2009. Land Fragmentation and Cropland Abandonment in Albania:

504 Implications for the Roles of State and Community in Post-Socialist Land Consolidation. *World*
505 *Dev.* 37(8), 1411-1423.

506 Sklenicka, P., Salek, M., 2008. Ownership and soil quality as sources of agricultural land fragmentation
507 in highly fragmented ownership patterns. *Landsc. Ecol.* 23(3), 299-311.

508 Song, W., Pijanowski, B. C., 2014. The effects of China's cultivated land balance program on potential
509 land productivity at a national scale. *Appl. Geogr.* 46, 158-170.

510 Su, S., Xiao, R., 2013. Spatially varying determinants of farmland conversion across Qiantang watershed,
511 China. *Environ. Manage.* 52(4), 907-916.

512 Su, S., Xiao, R., Zhang, Y., 2012. Multi-scale analysis of spatially varying relationships between
513 agricultural landscape patterns and urbanization using geographically weighted regression. *Appl.*
514 *Geogr.* 32(2), 360-375.

515 Su, S., Yang, C., Hu, Y., Luo, F., Wang, Y., 2014. Progressive landscape fragmentation in relation to cash
516 crop cultivation. *Appl. Geogr.* 53, 20-31.

517 Tan, S., Heerink, N., Kruseman, G., Qu, F., 2008. Do fragmented landholdings have higher production
518 costs? Evidence from rice farmers in Northeastern Jiangxi province, P.R. China. *China Econ. Rev.*
519 19(3), 347-358.

520 Tan, S., Heerink, N., Kuyvenhoven, A., Qu, F., 2010. Impact of land fragmentation on rice producers'
521 technical efficiency in South-East China. *NJAS-Wagen. J. Life Sci.* 57(2), 117-123.

522 The People's Government of Zhejiang Province, 2019. General Introduction of Zhejiang Province.
523 <http://www.zj.gov.cn/col/col1568516/index.html>.

524 Tiemann, L. K., Grandy, A. S., Atkinson, E. E., Marin-Spiotta, E., McDaniel, M. D., 2015. Crop rotational
525 diversity enhances belowground communities and functions in an agroecosystem. *Ecol. Lett.* 18(8),
526 761-771.

527 Van Hung, P., MacAulay, T.G., Marsh, S.P., 2007. The economics of land fragmentation in the north of
528 Vietnam. *Aust. J. Agr. Resour. Econ.* 51(2), 195-211.

529 Walz, U., Syrbe, R.-U., 2018. Landscape indicators – Monitoring of biodiversity and ecosystem services
530 at landscape level. *Ecol. Indic.* 94(2), 1-5.

531 Wan, G. H., Cheng, E., 2001. Effects of land fragmentation and returns to scale in the Chinese farming
532 sector. *Appl. Econ.* 33(2), 183-194.

533 World Bank, 2016. World Development Indicators. <https://data.worldbank.org/indicator/AG.LND>.
534 ARBL.HA.PC
535 Yang, H., 2014. China must continue the momentum of green law. *Nature* 509(7502), 535.
536 Yang, H., 2016. China's soil plan needs strong support. *Nature* 536(7617), 375.
537 Yang, W., Jin, Y., Sun, T., Yang, Z., Cai, Y., Yi, Y., 2018. Trade-offs among ecosystem services in coastal
538 wetlands under the effects of reclamation activities. *Ecol. Indic.* 92, 354-366.
539 You, H., 2017. Agricultural landscape dynamics in response to economic transition: Comparisons
540 between different spatial planning zones in Ningbo region, China. *Land Use Pol.* 61, 316-328.
541 Zhang, L., Huang, J., Rozelle, S., 1997. Land policy and land use in China. *Agricultural Policies in China*,
542 Organization for Economic Co-operation and Development, Paris, 71-77.
543 Zhao, T., Zhao, Y., Li, M., 2019. Landscape Performance for Coordinated Development of Rural
544 Communities & Small-Towns Based on "Ecological Priority and All-Area Integrated Development":
545 Six Case Studies in East China's Zhejiang Province. *Sustainability* 11(15), 4096.
546 Zhejiang Agricultural Department, 2016. The 13th Five-Year Plan for the Development of Modern
547 Ecological Cycle Agriculture in Zhejiang Province. Zhejiang Agricultural Department, Hangzhou.
548 http://www.zj.gov.cn/art/2016/8/15/art_5495_2181201.html