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Rice paddy fields' hidden value for typhoon protection in coastal areas

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ABSTRACT

Rice paddy cultivation has rooted in the Asian culture for thousands of years. At present, paddy fields as traditional agriculture in Asia provide not only ecosystem goods including rice and fibre production, but also other ecosystem services for human society. However, it is still not clear whether rice paddy fields like coastal wetlands provide typhoon protection function, although it is often regarded as a kind of artificial wetlands. We examined the relationship between the economic damages caused by typhoons and the presence of paddy fields with controlling for confounding variables including wind speed, typhoon duration and protective structures such as seawalls from 1989 to 2016 for China. Five economic regression models were proposed based on a variety of observation data coupled with GIS method. We found that paddy fields substitute for natural wetlands in mitigating the growing threat from typhoons in a changing climate. However, dry croplands appear not to provide a protective role to reduce typhoon damage. Using the multiple regression model we estimated the economic value of protection from typhoon damages provided by paddy fields to be an average of CNY 530,474/km^2 and a median of CNY 127,436/km^2 in China. This finding, if confirmed by renewed studies in the future, will have a significant impact on both ecosystem valuation of paddy fields and coastal management to mitigate the effect of natural disasters in a sustainable way.

1. Introduction

In Asia, traditional practice of culturing rice in paddy fields has existed for more than 2000 years. Zong et al. (2007) reported detailed evidences to reveal that coastal wetlands enabled first rice paddy cultivation in eastern China, 7700 calibrated years before present. This marked the important transition from foraging to farming in the human's cultural process (Lu, 1999). At present, China produced 2082 million tons of rice in 2014, accounting for 28% of global production (Wang et al., 2018; FAO, 2017). In terms of total area, China has the second largest amount of paddy fields (Xiao et al., 2005). The area of paddy fields is approximately 465,000 km^2 or only 4.9% of China's land area in 2015. However, this is more than double the area of natural wetlands which is 203,000 km^2.

Paddy fields provide not only rice production for food, but also a multiple of other ecosystem services. So far the diverse additional ecosystem services provided by paddy fields have been identified to be flood control, groundwater recharge, water purification, local climate mitigation, habitat for species, aesthetic landscape, gas regulation, soil erosion protection, fish culturing and other non-rice products (Natuhara, 2013; Xiao et al., 2005; Lowe, 2006). However, investigations of the value of ecosystem services provided by paddy fields have mainly focused on rice production. Continuing neglect of other ecosystem services related to the rice paddy fields, is an obvious weakness. Attempts so far to evaluate the ecosystem services rather than rice products provided by paddy fields are important for the public and decision makers as well as scientists. For instances, various studies showed that the rice paddy fields are able to provide flood control

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function (Matsuno, 2006, Kim et al., 2006; Huang et al., 2006; Onishi et al., 2004; Shimura, 1982). To overcome the problems caused by the structured dam, the local government of Niigata in Japan carried out a project to make use of the paddy fields as a flood control system successfully (Yoshikawa et al., 2010). Yoshikawa and his colleagues (2010) evaluated the paddy field to decrease the main channel discharge by 26% and to drop the water level by 0.17 m in the case of the largest observed rainfall event. In fact, the contribution of those additional ecosystem services by paddy fields to human welfare may be comparable to that of rice production (Pimentel et al., 1997). For example, Xiao et al. (2005) estimated the overall economic value of gas regulation provided by the rice paddy ecosystem ranged from CNY 10,080 to CNY 14,277 ha^{-1} per year (Euro 1 = CNY 10.7967, Jan. 2005 exchange rate).

Aside from the ecosystem functions referred above, the role of paddy fields in mitigating damages from typhoons has never been mentioned or studied in the literature. In contrast, wetlands are widely recognized for their pivotal role in mitigating typhoon damages and a number of studies have been carried out to estimate the value of typhoon protection provided by wetlands (Ouyang et al., 2018; Costanza et al., 2008; Farber, 1987). The paddy fields have been argued in the literature to be a kind of artificial wetlands due to their similar characteristics. Could it therefore be expected to provide some alike ecosystem functions as wetlands, to say the typhoon mitigation? If yes, how great is its typhoon protection value? That is what the government and scientists demand to know. Unfortunately, there are no answers yet. In this paper, we have conducted an empirical analysis to examine the relationship between typhoon damages and paddy fields in China from 1989 to 2016.

We developed five regression models following the method proposed by Costanza et al. (2008) to examine the link between the economic damages of typhoons and the presence of paddy fields in the swath of typhoons landing the coasts. Using statistical analysis to further confirm the hypothesis of unique typhoon mitigation service attached to paddy fields, we controlled for important, confounding factors including wind speed, typhoon duration and protective structures (i.e., seawalls). We also examined the dry croplands to check the relationship between its presence in the typhoon swath and the relative economic loss, as the croplands in China mainly consists of dry croplands and paddy fields. For all five regression models, the ratio of total economic damage by typhoon to gross domestic production (TD/GDP) in log transformation was the dependent variable. Model 1 is a simple base model in which only paddy fields together with a constant were involved. Other variables including wind speed, typhoon duration, protective structures such as seawalls and dry croplands were progressively added from Model 2 to Model 5.

We presented an initial estimate of typhoon mitigation service value provided by the paddy fields that is, to our knowledge, the first to be based on an empirical analysis of 127 typhoons over 28 years. This finding, if confirmed, will stimulate additional researches and debates on the paddy field's ecosystem services and valuations. This will further have significant impact on coastal management for considering paddy fields as a substitute for wetlands where conserving or restoring wetlands is not possible, to provide typhoon mitigation along the Chinese coasts.

2. Methods and data

To determine the relationship between the relative economic damage of typhoon and paddy fields or dry croplands, we proposed five economic regression models (see below from Model 1- Model 5) based on a multiple of databases. The economic model aims to check if the existence of paddy fields in the swath of the typhoon could affect the economic damage caused by typhoons. Model 1 is a base model in which only one independent variable (i.e., the paddy fields) was considered. Other relevant variables such as wind speed, typhoon duration and structured defences were added progressively in the Model 2 to the Model 4. The variable of dry croplands was included in the Model 5 as well to examine the relationship between the dry croplands and the relative economic damages caused by the typhoon. Multiple regression analyses were conducted by Eviews 10.

$$\text{Model1: } \ln(\mathrm{TD_i/GDP_i}) = \alpha + \beta_1\ln(\mathrm{paddy_i}) + \mu_\mathrm{i} \tag{1}$$

$$\text{Model2: } \ln(\mathrm{TD_i/GDP_i}) = \alpha + \beta_1\ln(\mathrm{paddy_i}) + \beta_2\ln(\mathrm{wind_i}) + \mu_\mathrm{i} \tag{2}$$

$$\text{Model3: } \ln(\mathrm{TD_i/GDP_i}) = \alpha + \beta_1\ln(\mathrm{paddy_i}) + \beta_2\ln(\mathrm{wind_i}) + \beta_3\ln(\mathrm{duration_i}) + \mu_\mathrm{i} \tag{3}$$

$$\text{Model4: } \ln(\mathrm{TD_i/GDP_i}) = \alpha + \beta_1\ln(\mathrm{paddy_i}) + \beta_2\ln(\mathrm{wind_i}) + \beta_3\ln(\mathrm{duration_i}) + \beta_4 *\mathrm{seawall_i} + \mu_\mathrm{i} \tag{4}$$

$$\text{Model5: } \ln(\mathrm{TD_i/GDP_i}) = \alpha + \beta_1\ln(\mathrm{paddy_i}) + \beta_2\ln(\mathrm{wind_i}) + \beta_3\ln(\mathrm{duration_i}) + \beta_4 *\mathrm{seawall_i} + \beta_5\ln(\mathrm{dry_i}) + \mu_\mathrm{i} \tag{5}$$

In which ln(TD/GDP) indicates the natural log of damage per unit gross domestic production in the typhoon *i*'s swath; TD is the total economic damage caused by typhoon and GDP is the gross domestic production in the typhoon *i*'s swath; α is constant, $\mathrm{paddy_i}$ represents the area of paddy fields in the typhoon *i*'s swath; $\mathrm{wind_i}$ is for wind speed at land fall of typhoon *i*; $\mathrm{duration_i}$ is for typhoon *i*'s duration in hours; $\mathrm{seawall_i}$ refers to the length of protective structures such as seawall in the typhoon *i*'s swath. μ_i is a random. We expected $\beta_2 <0$, $\beta_3 <0$ and $\beta_4 < 0$.

A variety of data were collected from pertinent web sites and official annual reports. Historical typhoons hitting China from Unisys Weather (2017) provided both wind speeds at landfall, typhoon duration and typhoon trajectories. Both wind speed at landfall and typhoon duration as major variables were added in the regressions. The typhoon trajectory information was used to calculate the swath for each typhoon following Willoughby and Rahn (2004) as described below:

$$R_i = 51.5\exp(-0.0223V_i + 0.0281\varphi_i) \tag{6}$$

where the wind radius, $\mathrm{R_i}$, is a function of combining wind speed ($\mathrm{V_i}$) and the latitude position (φ_i) at a specific time *i*. We proposed a varied typhoon swath, which is a belt area with a central line along the trajectory of the typhoon approaching inland and a wind impact radius$\mathrm{R_i}$.

Economic damage caused by typhoons from 1989 to 2016 were extracted from the annual Marine Disaster Bulletin (MDB, 2016) issued by the State of Ocean Administration (SOA), China. Totally, 127 typhoons with consequent economic damage (TD) were used in the regressions. The total economic damage (TD) from MDB is comprehensive including properties, roads, bridges, fishing ships, human lives and so on that were damaged by the typhoons.

Population data for 1990 and 2015 were found at SEDAC (Socioeconomic Data and Applications Center at Columbia University), while population data for 1995, 2000, 2005 and 2010 were obtained from RESDC (Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences). The study period covered 28 years from 1989 to 2016. Population data for other years were interpolated based on data at specific years available. Temporal statistical GDP data for Chinese coastal provinces were obtained from the National Bureau of Statistics of China. Both the population census data and GDP statistic data were used for calculating the spatially explicit gross domestic product (GDP) in each typhoon's swath. The ration of TD/GDP represented the relative economic damage of each typhoon.

A variety of Landsat data with 30 m or 60 m resolution for 1980, 1990, 2000, 2010 and 2015 covering the entire china's coast were downloaded from U.S. Geological Survey and were then used to retrieve the spatiotemporal distribution of hard engineered defence (i.e.,

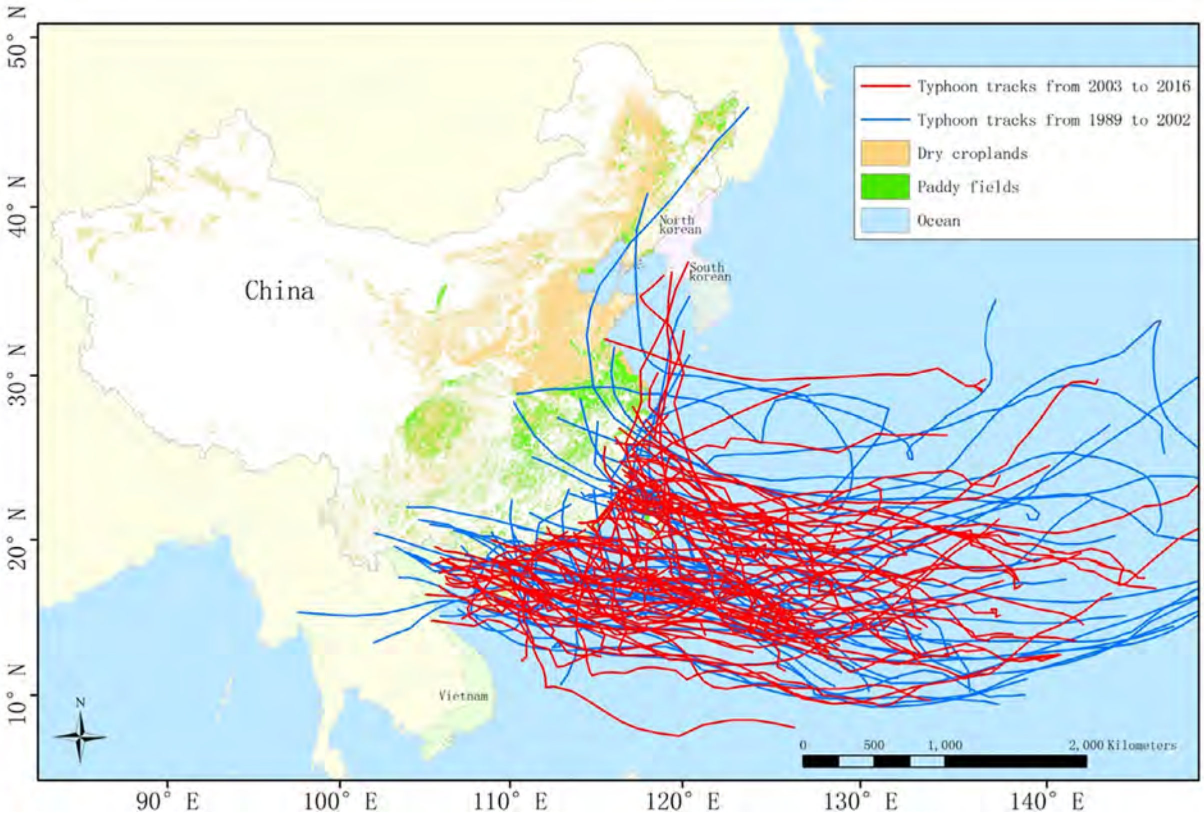


Fig. 1. Distribution of paddy fields and dry croplands for China in 2015. Tracks of 127 typhoons hitting China and causing economic damage from 1989 to 2016 were mapped. Typhoons during 1989–2002 were marked in dark blue and those during 2003–2016 were highlighted in red.

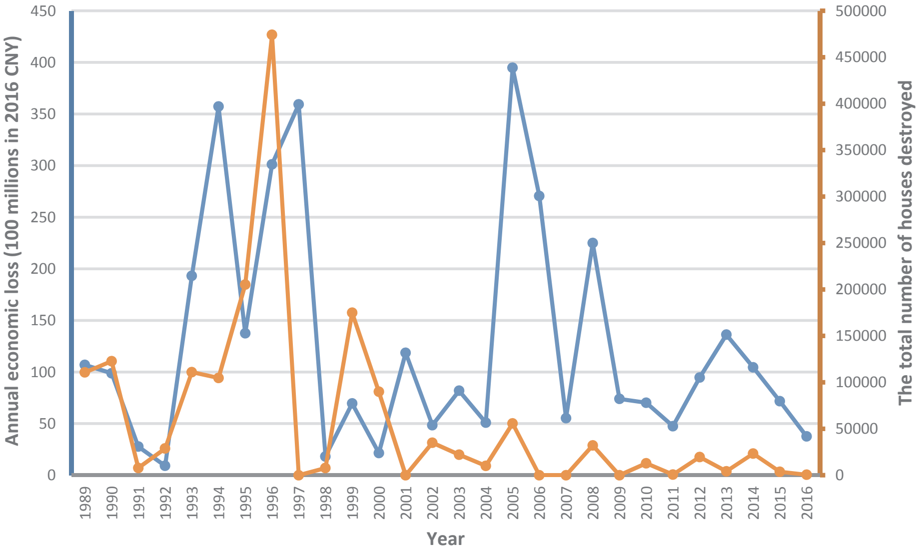


Fig. 2. Statistics for annual economic loss caused by typhoons and the number of houses destroyed by typhoon in China from 1989 to 2016. Blue line represents the total economic damage of typhoon for each year and the orange line is the yearly sum for houses destroyed by typhoons.

seawalls) along the China's coast by utilizing remote sensing and GIS technologies.

The 1 km*1 km resolution National Landover dataset came from Resource and Environment Data Cloud Platform (RESDC) for six specific years of 1990, 1995, 2000, 2005, 2010 and 2015. This dataset included mapping of both paddy fields and dry croplands, which were grouped into the major category of agriculture.

The typhoon swaths were then overlaid on the spatially explicit data on paddy fields, dry croplands and coastal engineered structures to obtain the area of paddy fields, the length of coastal engineered structures and the area of dry croplands exposed within each typhoon's swath.

3. Results

3.1. Typhoons tracks and trends

From 1989 to 2016, China received 127 typhoon hits with consequent economic damage, which can be seen in Fig. 1. The Marine Disaster Bulletin issued by the State of Ocean Administration (SOA), China documented the total economic loss for each of the 127 typhoons. All economic losses of 127 historical cases were then converted to 2016 CNY based on Consumer Price Index by Statistics of China. Generally, southern provinces were hit by typhoons more seriously than northern ones over the past 28 years in China. Over the 14-year period of from 1989 to 2002, there were 47 typhoons hitting China, while the number of typhoons hitting China nearly doubled to 80 over the period 2003–2016. Croplands in China are classified in two categories: dry croplands and paddy fields. From 1990 to 2015, the area of dry croplands has increased slightly from 1,299,375 km^2 to 1,321,053 km^2, while paddy fields have decreased slightly from 472,421 km^2 to 464,950 km^2 in area. Fig. 1 shows the distribution of both paddy fields and dry croplands in China for the recent year of 2015. Paddy fields are spatially varied in China, southern provinces have more paddy fields than the northern ones; eastern coastal areas have more than western inlands do. Economic loss caused by the 127 typhoons can be seen in the Fig. 2. Among the 127 typhoons, only 58 cases have a record of houses destroyed by the specific typhoons. The annual number of houses destroyed by typhoons is also shown in Fig. 2. The main trends over decades in China from both Figs. 1 and 2 showed: 1) paddy fields decreased as dry cropland increased in terms of area; 2) typhoons hit China more frequently than before; 3) both the annual economic loss and the annual number of houses destroyed caused by typhoons in China have decreased sharply (Fig. 3).

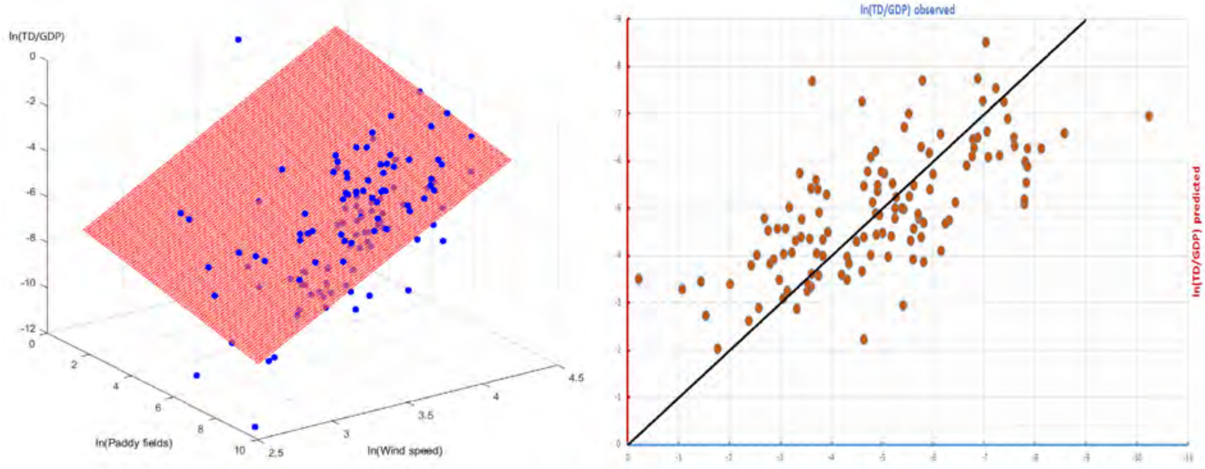
3.2. Model regressions

Our regression results suggested that the presence of paddy fields in the typhoon swath did play a protective role to affect typhoon damage. The coefficient on paddy fields was negative and statistically significant ($p < 0.05$), when this variable was the only regressor in model 1. It remained significant and changed little in magnitude as controls such as wind speed, typhoon duration, protective structures and dry croplands were progressively added for paddy fields (see Table 1 for coefficient estimates on paddy fields). Aside from the paddy fields, the other significant determinants of economic damage by typhoon include wind speed at landfall, typhoon duration and the presence of seawalls. As expected, both wind speed and typhoon duration significantly affected the relative economic damage caused by typhoon. The relative economic damage increases as the 3.12–3.69 power of the wind speed at landfall during typhoon and the 1.21 power of the typhoon duration. To control for the effect of protective structures along the China's coast, we included a variable capturing the presence of seawalls in the regression model. The negative sign of the seawalls suggests that the longer the seawalls in the typhoon swath the lower the typhoon damage. The coefficient is negative and significant implying that in areas where seawalls were present, coastal community suffered less economic damage of typhoon. On average, the expected reduction in the log count of relative economic damage (TD/GDP) with a kilometre increase in seawall cover is 0.00084 as shown in Model 4. As a final check, we added the area of dry croplands in the typhoon swath to the model 5 in Table 1. However, dry croplands did not show such a link with typhoon damage, as dry croplands representing independent variable was not significant in the Model 5 ($p = 0.3283 > 0.1$). This finding agreed with our expectation that paddy fields is comparable to natural wetlands to provide similar storm/typhoon protection services, while dry croplands is not able to do that.

Using Model 4, we predicted an average marginal value of CNY 530,474/km^2 and a median marginal value of CNY 127,436/km^2 provided by paddy fields for typhoon protection based on estimations for all 127 cases. That means a gain of 1 km^2 of paddy fields corresponds to an average CNY 530,474 [US $83,803] (median = CNY 127,436 [US $20,132]) decrease in economic damage loss from specific typhoons. This estimation is very reasonable if we compared the results derived in this paper with a previous work by Costanza et al. (2008). Costanza and his colleagues estimated an average value of US $3.3 million/$km^2$ and a median US $500,000/$km^2$ protection value of U.S. coastal wetlands from storm damage. Obviously, paddy fields provide less valuable storm/typhoon protection than the coastal wetlands do, which agreed with our anticipation.

4. Discussion

Paddy fields have a root in Asian culture for thousands of years. People have focused mainly on its rice production rather than other ecosystem services. To our knowledge, only limited ecosystem services including gas regulation, flood control, groundwater recharge, water purification, local climate cooling, habitat for species, soil erosion



(a)

(b)

Fig. 3. Regression results: (a) The regression Model 2: ln(TD/GDP) = −15.9936 + 3.6875*ln(wind speed at landfall)-0.2408*ln(area of paddy fields in typhoon swath), which is highlighted by red mesh and the observed 127 historical cases were scattered in blue points ($R^2 = 0.46$); (b) ln(TD/GDP) observed vs. predicted for Model 4 with fitness $R^2 = 0.57$.

Table 1
Estimates of regression coefficient on variables included.

Model and variables	Coefficient estimate	R^2
Model 1 (base model): $\ln(TD/GDP) = \alpha + \beta_1*\ln(paddy)$		0.03
Constant	−2.997***	
Paddy fields in typhoon swath (km^2)	−0.278**	
Model 2 (add wind speed to above): $\ln(TD/GDP) = \alpha + \beta_1*\ln(paddy) + \beta_2*\ln(wind)$		0.46
Constant	−15.994***	
Paddy fields in typhoon swath (km^2)	−0.241**	
Wind speed at landfall (m/s)	3.687***	
Model 3 (add typhoon duration to above): $\ln(TD/GDP) = \alpha + \beta_1*\ln(paddy) + \beta_2*\ln(wind) + \beta_3*\ln(duration)$		0.55
Constant	−19.971***	
Paddy fields in typhoon swath (km^2)	−0.332***	
Wind speed at landfall (m/s)	3.289***	
Typhoon duration (hours)	1.210***	
Model 4 (add seawall to above): $\ln(TD/GDP) = \alpha + \beta_1*\ln(paddy) + \beta_2*\ln(wind) + \beta_3*\ln(duration) + \beta_4*seawall$		0.57
Constant	19.858***	
Paddy fields in typhoon swath (km^2)	−0.234**	
Wind speed at landfall (m/s)	3.139***	
Tyhoon duration (hours)	1.211***	
Length of seawall in typhoon swath (km)	−0.00084**	
Model 5 (add dry croplands to above): $\ln(TD/GDP) = \alpha + \beta_1*\ln(paddy) + \beta_2*\ln(wind) + \beta_3*\ln(duration) + \beta_4*seawall + \beta_5*\ln(dry)$		0.57
Constant	−20.226***	
Paddy fields in typhoon swath (km^2)	−0.304**	
Wind speed at landfall (m/s)	3.116***	
Typhoon duration (hours)	1.210***	
Length of seawall in typhoon swath (km)	−0.00095**	
Dry croplands in typhoon swath (km^2)	0.134*	

Note: ***Statistically significant at 1% level.
**Statistically significant at 5% level.
*Not significant (coefficient is marked in red).

protection, fish culture and other non-rice products were identified to relate to paddy fields in the literature. Here, we conducted an empirical analysis between typhoon damage data and paddy fields in the typhoon swath for China from 1989 to 2016 and we initially found overwhelming evidence of typhoon mitigation service provided by paddy fields. To confirm the new finding, we also conducted the same analysis for dry croplands, the other major category of agriculture in China. However, dry croplands are not recognized for their ability to provide typhoon mitigation, as it was not significant variable in the regression model for statistical analysis. Our results concluded that the presence of paddy fields reduces the economic damage caused by typhoon, which implied that the paddy fields is comparable to coastal wetlands to provide a similar typhoon protection function. Our finding sheds light on the debate of both ecosystem valuation linked to paddy fields and coastal management to mitigate natural disasters in the future.

4.1. Validation

We evaluated the typhoon protection value of paddy fields in monetary units. Our conservative estimates showed that an average value of typhoon protection by paddy fields is CNY 530,474/km^2 [US $83,803/$km^2$] and the median value is CNY 127,436/km^2 [US $20,132/$km^2$]). It is the first effort to identify the typhoon protection function of paddy fields and to put a value on it in the literature, hence we have no way to directly compare our results with others. However, we can compare such an estimation either with typhoon protection value provided by coastal wetlands or with valuations of other ecosystem services provided by paddy fields in previous publications. In terms of storm/typhoon protection, we do not expect paddy fields to provide as large effect as coastal wetlands do. Therefore, it is reasonable if the typhoon/storm protection value attached to coastal wetlands in the literature is higher than our estimation for paddy fields. Ouyang et al. (2018) showed that the values of wetlands for cyclone mitigation ranged from US $3,906,700/$km^2$ to US $4,924,000/$km^2$ in Australia, while the values ranged from US $364,700/$km^2$ to US $5,850,220/$km^2$ in China. Another estimation for valuing storm protection by coastal wetlands was done by Costanza et al. (2008). Costanza and his colleagues estimated an average annual value of US $3.3 million/$km^2$ and a median US $500,000/$km^2$ protection value of U.S. coastal wetlands from storm damage. By comparison, our estimation is much lower than their estimated values for coastal wetlands, which agreed with our anticipation that paddy fields provide less valuable typhoon protection than the coastal wetlands do. Over the past two decades, a number of studies have investigated the ecosystem services and their values provided by paddy fields. We collected some references listed in Table 2 to show other important ecosystem services and their estimated values, including gas regulation, water purification, flood control, biodiversity maintenance, cooling effect and rice production. Water purification and flood control represented relatively high economic values (CNY 69 million/km^2 for water purification and CNY 926,568/km^2 for flood control). Biodiversity maintenance represented a low value of CNY 71,537/km^2 according to the work by Xie et al. (2015). Our estimated storm protection value for paddy fields ranging from CNY 1112/km^2 to CNY 25.96 million/km^2 with a median value of CNY 127,436/km^2 and an average value of CNY 530,474/km^2 just fit in the range of values attached to ecosystem services summarized in Table 2 (from CNY 1008/km^2 to CNY 69 million/km^2). That is to say, the contribution of storm protection service provided by paddy fields are comparable to that of

Table 2
Important ecosystem services provided by paddy fields in addition to typhoon mitigation.

Ecosystem services	Value	Refs.
Gas regulation	CNY 1,008–1,427,700/km^2	Xiao et al. (2005)
Water purification	CNY 69 million/km^2 [JPY 1.2*1000/m^2]	Natuhara (2013), Shiratani et al. (2006)
Flood control	CNY 926,568/km^2	Xie et al. (2015)
Biodiversity maintenance	CNY 71,537/km^2	Xie et al. (2015)
Climate regulation: cooling effect	CNY 178,637/km^2	Zhang et al. (2017)
Rice production	CNY 426,221/km^2	Zhang et al. (2017)

gas regulation, water purification, cooling effect and rice production in the same order of magnitude.

The typhoon mitigation service identified in this paper should be grouped into the category of “disturbance regulation”, which was defined by Costanza et al. (1997). Like flood control, typhoon mitigation by paddy fields has positive economic value to human welfare. If this finding is confirmed by other scientists and recognized by decision makers, paddy fields is additionally expected to afford protection from typhoons, if saltwater tolerant rice is cultivated along the Chinese coast in the future. Particularly, a news by Nature in June 2018 reported that strains of saltwater tolerant rice (i.e., so called seawater rice) have been trialled in experimental paddies along the Qingdao coast, China. Undoubtedly, this potentially encourages the full application of paddy fields for seawater rice along the China’s coast to provide both food production and storm protection. Here it is suggested to combine the existing man-made structures with natural wetlands and/or paddy fields to increase coastal typhoon protection in China.

4.2. Future studies on mechanism

The theory of “paddy fields mitigating typhoon” was established merely based on our empirical analysis in an economic way in this paper. More evidence, especially studies on bio-physical models, field tests and natural experiments, are needed to confirm or challenge this paradigm. Renewed studies on the mechanism by which paddy fields attenuate damages are important to support and refine this estimate in the future.

4.3. Limitations

There were uncertainties and limitations in our estimates. Firstly, R^2 is only 0.57 for the regression model 4, which means only 57% of the relative damage (TD/GDP) can be explained by the proposed model 4. This weak R^2 may be due to a combination of a large variance of ln(TD/GDP) and imprecise geographic data for paddy fields. The variance of ln (TD/GDP) in the sample was 4.05, which is relatively high for log-transformed variable. The geographic information on paddy fields were extracted from the National Landcover dataset, which is limited to specific years including 1990, 1995, 2000, 2005, 2010 and 2015. While, 127 historical typhoons started from 1989 to 2016. Future studies are expected to improve the valuation model if the area data for paddy fields can be obtained for covering each year of the typhoon period. Secondly, the relationship between the typhoon and paddy fields were examined and confirmed economically in this paper, which did not describe evidence about the mechanistic aspects of typhoon protection provided by paddy fields. We hope that future researches and debates can center on the direct and indirect mechanism by which paddy fields is able to control wave energy for typhoon mitigation. Finally, the object that we addressed in this paper is limited to active paddy fields not fallow paddy fields. The economic value of mitigating typhoon is hence attached to active paddy fields.

5. Conclusion

So far there is no existing research that studied the typhoon protection function attached to the rice paddy fields. In this paper, we initially reported a striking finding of typhoon protection service provided by paddy fields based a long-term observation over 28 years from 1989 to 2016 with a coupling of economic regression model with GIS method at a national scale (in this case for China). Thus, this paper has revealed, for the first time, a significant effect of paddy fields being comparable to natural wetlands to mitigate the growing threat from typhoons in a changing climate. This finding, if confirmed by renewed studies in the future, will have a significant impact (surprise) on both ecosystem valuation of paddy fields and coastal management to mitigate the effect of natural disasters, which suggests that not only hard engineering and wetlands, but paddy fields, especially saltwater tolerant rice can be considered to be cultured as an alternative along the Chinese coasts, where neither constructing seawalls nor conserving wetlands is possible, to reduce economic damage caused by typhoons. Particularly, a news by Nature (volume 558, June 7, 2018) reported that strains of saltwater tolerant rice (i.e., so called seawater rice) have been trialed in experimental paddies along the Qingdao coast, China. Undoubtedly, this potentially encourages the full application of paddy fields for seawater rice along the China’s coast to provide both food production and storm protection, which is one stone killing two birds.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2019.105610.

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