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Values of the Farmland Ecosystem Services of Qingdao City, China, and their Changes

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Abstract: The values of farmland ecosystem services are composed of several components: provisioning service value, regulating service value, supporting service value and cultural service value, so it is important to make a full assessment of the values of farmland ecosystem services for agriculture and farmland protection. Here, we assessed the values of farmland ecosystem services in Qingdao City in 1997, 2002, 2007, 2012 and 2017 by using various methods (market value method, carbon tax method, afforestation cost method, substitute cost method, equivalent factor method, etc.) based on establishing an assessment index system for the farmland ecosystem services value. The results show that the total yearly value of farmland ecosystem services increased from 499.74×10^8 Yuan to 681.74×10^8 Yuan in the period of 1997–2017, and the yearly value of farmland ecosystem services per hectare increased from 6.57×10^4 Yuan to 9.73×10^4 Yuan. The product provisioning service, carbon fixation service and oxygen release service, as well as the soil conservation service, are the main farmland ecosystem services, and the proportions of these four ecosystem service values to the total value of farmland ecosystem services in Qingdao City were large and kept increasing. Some countermeasures are put forward to adequately use the indirect service value of the farmland ecosystem and provide improved well-being for humans, such as protecting and wisely using farmland, developing agriculture that is rooted in local conditions, promoting agricultural production efficiency, speeding up construction of modern agriculture gardens, deepening the supply-side structural reform of agriculture, developing agricultural eco-tourism, etc.

Key words: Qingdao City; farmland; ecosystem services value; assessment

1 Introduction

The ecosystem provides humans with food and raw materials, and it is indispensable for sustainable development (Luo et al., 2019). According to the Comprehensive Report on Millennium Ecosystem Assessment issued by the United Nations in 2005, the intensive use of ecosystem services by humans in the past 50 years has increased human well-being(Millennium Ecosystem Assessment, 2005); however, it has also significantly destroyed the Earth's ecosystem, resulting in ecosystem degradation, the reduction of ecological assets and the decline of biodiversity (Carpenter et al., 2006; Narducci et al., 2019). Therefore, understanding the optimal coverage of ecosystem services (Alejandre et al., 2019), accurately assessing the ecosystem service value and making a full assessment of the relationship between ecosystem services and human well-being are important for achieving sustainable development (Parkes, 2006).

Farmland is a semi-natural ecosystem in which human beings produce agricultural products using natural resources and artificial inputs (Xie and Xiao, 2013). The farmland ecosystem has both natural attributes and socio-economic attributes, with the characteristics of purpose, openness,

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efficiency, variability, vulnerability, external input dependence, and others (Yin et al., 2006). Farmland ecosystem services include provisioning services, regulating services, supporting services and cultural services (Simpson, 2019). In addition, the farmland ecosystem also functions in forming social security, culture and entertainment for improving human well-being and other cultural services (Bai et al., 2010; Zhang and Qiu, 2018).

Since the end of the 20th century, great attention has been paid to evaluating ecosystem services (Costanza et al., 1997). At present, the research on ecosystem service value mainly focuses on natural ecosystems of forest, grassland, wetland (Costanza et al., 2014), farmland (Marinidou et al., 2019), and others. Early research on farmland ecosystem service value mainly focused on the provisioning service, as well as the quality and yield of agricultural products, while it did not fully recognize the regulating service, supporting service and cultural service (Porter et al., 2009; van den Belt and Blake, 2014), or the impact of land use and farmland abandonment on the farmland ecosystem services value (Lin et al., 2018; Sil et al., 2019). Some practical techniques for the quantitative assessment of farmland ecosystem services have been developed to meet the requirements of different end users (Tzilivakis et al., 2019), and the loss of farmland ecosystem services value caused by the negative environmental impact of agricultural production activities needs to be strengthened (Lu et al., 2016). Because the farmland ecosystem is greatly affected by human activities, it is difficult to measure the value of farmland ecosystem services, especially its non-market value (Yang et al., 2005; Du et al., 2008).

As an international metropolis with a large population, the protection and wise use of the farmland ecosystem is particularly important for Qingdao City, especially at a time when its industrial economy is developing rapidly. On the basis of the ecosystem services value system of the Millennium Ecosystem Assessment, the values of farmland ecosystem services in Qingdao City in 1997, 2002, 2007, 2012 and 2017 were evaluated. Analyzing the value changes of farmland ecosystem services caused by agricultural production and land use changes can provide a scientific basis for agricultural production decision-making, rational allocation of agricultural resources, formulation of farmland utilization management policy and calculation of farmland ecological compensation standards in Qingdao City. In addition, this analysis can also help the public to fully understand the ecological utility of the farmland ecosystem, enhance the awareness of social public protection and the rational use of farmland, and promote the sustainable development of regional agriculture.

2 Overview of the study area

Qingdao City, Shandong Province (35°35′–37°09′N, 119°30′–121°00′E) is located in the southwest of Shandong Peninsula, northern China. It is bordered by the Yellow Sea in the southeast, and by Yantai City, Weifang City and Rizhao City in the northeast and southwest, respectively. The terrain is high in the east and low in the west. The main types of landforms include plains, hills, mountains and coastal lowlands, accounting for 46.33%, 41.04%, 9.34% and 3.29% of the total land area, respectively. Among them, the plain is the main production area of grains, peanut, vegetables and cotton. Most of the hills have been reclaimed into farmland, with plantings of economic forests or wheat, corn, peanuts, sweet potato and so on; the mountainous areas are mostly used for forest, orchards and tourism; and the coastal lowlands are mostly used for maricultural ponds and salterns (Fig. 1). The soils are classified into brown soil, fluvo-aquic soil, cinnamon soil, lime concretion black soil, saline soil, paddy soil, and others. Among them, brown soil is the largest, most widely distributed type in the low mountains and hilly areas, accounting for about 58.5% of the available agricultural land, and most of it has been reclaimed into farmland. The temperate monsoon climate of the research area has the characteristics of four distinct seasons, with abundant rainfall in summer. The average annual temperature of Qingdao City is 12.0 ℃, the average annual precipitation is 687.3 mm, and the precipitation is mostly concentrated from June to August. The rivers of Qingdao City belong to the Dagu River system, the Beijiaolai River system and the system of coastal rivers.

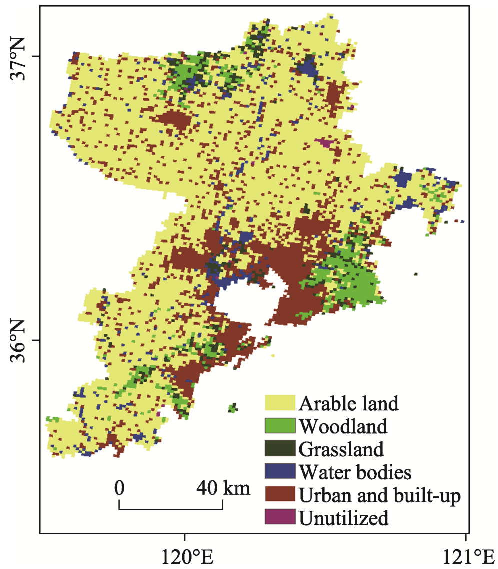

Fig. 1 The types and distribution of land use in Qingdao City in 2018

Qingdao City has 7 districts and 3 county level cities: Shinan District, Shibei District, Licang District, Laoshan District, Huangdao District, Chengyang District, Jimo District, Jiaozhou City, Pingdu City and Laixi City. In 2018, there are a permanent resident population of 939.48×10^4 people in the city. At the end of 2017, there was 51.86×10^4 ha of cultivated land, mainly distributed in Laixi City, Pingdu City, Jiaozhou City, Jimo District and Huangdao District. The main crops are wheat, corn, peanut, potato, vegetables and fruits, and the total grain production of Qingdao City accounts for 6.29% of that of Shandong Province.

3 Research methods

3.1 Construction of the evaluation index system and data sources

According to the Millennium Ecosystem Assessment issued by the United Nations in 2005 and the actual agriculture in Qingdao City, the farmland ecosystem services in Qingdao City are divided into two categories, direct ecosystem services and indirect ecosystem services. Direct ecosystem services mainly refer to provisioning services, that is, agricultural product production and provisioning, while indirect ecosystem services mainly include regulating services, supporting services and cultural services. According to the above classification of farmland ecosystem services, the evaluation index system for farmland ecosystem services in Qingdao City was constructed, including 7 indexes and 10 calculation methods (Table 1).

The data of population, types and yields of agricultural products, soil characteristics, water resources and their utilization, agricultural production and living standards, and others, were obtained from the Qingdao Statistical Yearbooks, Shandong Statistical Yearbooks and China Price Yearbooks for 1998, 2003, 2008, 2013 and 2018; the Statistical Bulletin of National Economic and Social Development in Qingdao City, the Statistical Bulletin of National Economic and Social Development of Shandong Province in 1997, 2002, 2007, 2012 and 2017; as well as the History and Annuals of Qingdao—Agriculture Annuals, the History and Annuals of Qingdao—Physical geography/Meteorology annuals and other miscellaneous documents.

3.2 Methods of evaluating farmland ecosystem service values

3.2.1 Value of product provisioning service

Agricultural product production and provisioning are the most important farmland ecosystem services. The farmland in Qingdao City mainly produces grains, vegetables, melons and fruits and economic crops, among which wheat, corn, soybean, sweet potato and potato are the main food crops, while peanut, cotton and tobacco are the main economic crops. The value of the product provisioning service of the farmland ecosystem is calculated by the market value method, according to the current average market price of all the relevant types of agricultural products.

3.2.2 Values of carbon fixation service and oxygen release service

Atmospheric carbon dioxide is fixed in the form of organic carbon in agricultural products and soil organic carbon; meanwhile, oxygen is released through photosynthesis. According to the moisture contents and economic coefficients of the various crops, the net primary production, carbon fixation and oxygen release of the different crops can be calculated (Yan et al., 2007), and then the values of the carbon fixation service and the oxygen release service of the farmland ecosystem in Qingdao City can be calculated by several methods: carbon tax method, afforestation cost method, industrial oxygen production method, etc. In these calculations, only the carbon fixation and oxygen release services provided by the farmland ecosystem during the growing period of the different kinds of crops are taken into account, while the sink or source effects of carbon in the harvest and in the process of transformation into various ecosystems are excluded (Yang et al., 2005).

3.2.3 Value of water conservation service

The farmland ecosystem can prolong the formation of surface runoff and reduce the surface water loss through crop interception of precipitation, and it can also make use of the water maintained by soil capillary force to meet the needs of current plant growth and future water supply in order to achieve the water conservation service. The water conservation service value of the farmland ecosystem is composed of the value of the crop interception of precipitation service and the value of the farmland soil water retention service. Because the water conservation service of the farmland ecosystem has a similar function to that of a reservoir, its value is calculated by the alternative cost method, using the cost of constructing a reservoir with the same water conservation capacity.

3.2.4 Value of climate regulating service

Crop transpiration and farmland evaporation increase the humidity in the atmosphere of the surrounding farmland. Mesoscale convection induced by thermal and dynamic effects of the farmland ecosystem can promote the formation of precipitation and produce a rain enhancement effect (Zhang et al., 2009). Because crop transpiration and farmland evaporation are difficult to observe, the equivalent factor method is used to evaluate the climate regulating service value of the farmland ecosystem in Qingdao City. Based on a questionnaire survey of 200 Chinese ecologists, and according to the estimated results of the value of global ecosystem services (Costanza et al., 1997), a value equivalence scale of the ecological services per unit area of the terrestrial ecosystem in China was developed. The economic value of yearly grain production of farmland per hectare was calculated with the national average grain yield level defined as 1 value equivalent factor for the farmland ecosystem services (Xie et al., 2003; Xie et al., 2005). One value equivalent factor of farmland ecosystem services represents the proportional contribution of the specific service to the food production service of the farmland ecosystem. For example, the value equivalence ratio of the climate regulating service to the food production service is 0.89:1; that is, the value of the climate regulating service is 0.89 times of that of the

Table 1 Evaluation index system of the farmland ecosystem service values in Qingdao City

Service type	Evaluation index	Meaning of index	Evaluation method	Calculating formula	Meaning of parameters
Provisioning service	Product provisioning service	Agricultural product production and provisioning	Market value method	$V_A=\sum_{i=1}^{n} m_i \times p_i \times q_i$	V_A is the value of agricultural product provisioning service (Yuan), p_i is the agricultural product price of type i per kilogram (Yuan kg^{-1}), q_i is the net production of agricultural product of type i per hectare (t ha^{-1}), m_i is the planting area of type i agricultural product (ha)
Regulating service	Carbon fixation service	Fixation of CO_2 by the process of photosynthesis	Carbon tax method, afforestation cost method	$NPP=\sum_{i=1}^{n}\frac{Y_i(1-w_i)}{f_i}$ V_C=1.68×NPP×R_C×P_C	NPP is the net primary production of crops (t yr^{-1}), Y_i is the economic yield of type i crop (t), w_i is the moisture content of type i crop, f_i is the economic coefficient of type i crop, V_C is the carbon fixation value of the farmland ecosystem (Yuan), Pc is the cost of carbon fixation, Rc is the content in CO_2, 27.27% (Liu et al., 2015)
	Oxygen release service	Release of O_2 By the process of photosynthesis	Industrial oxygen production method, afforestation cost method	V_O=1.20×NPP×P_O	V_O is the total oxygen release service value of the farmland ecosystem (Yuan), P_O is the cost of oxygen production
	Water conservation service	Intercepting precipitation by the crop	Substitute cost method	V_1=S×P×K×P_W	V_1 is the service value of crop interception of precipitation (Yuan), S is the area of farmland (ha), P is the average annual precipitation in Qingdao City (mm), K is the ratio of crop precipitation interception (%), the ratio of precipitation interception for general crops is 5% (Wu et al., 2017), P_W is the cost of reservoir construction (Yuan m^{-3})
		Maintaining water by the soil	Substitute cost method	V_2=S×C×H×P_W	V_2 is the value of the maintaining water service of soil (Yuan), C is the non-capillary porosity of soil (%), H is the thickness of soil (cm)
	Climate regulating service	Enhancing humidification and rain	Equivalent factor method	$V_M=0.89C_0=\frac{1}{7}\times\left(\sum_{i=1}^{n} m_i \times p_i \times q_i\right)\times\frac{1}{T}$	V_M is the climate regulating service value of farmland (Yuan), C_0 is the food producing and provisioning service value of the farmland ecosystem per hectare (Yuan ha^{-1}), m_i is the area of type i food crop (ha), p_i is the price of type i food crop (Yuan kg^{-1}), q_i is the per unit yield of type i food crop (t ha^{-1}), T is the total planting area of food crops (ha)
Supporting service	Soil conservation service	Maintaining soil nutrients	Shadow price method	$V_{S1}=Q_S\times\sum S_j\times C_j\times P_j$ $Q_S=S\times(E_p-E_r)$	V_{S1} is the soil nutrient maintainence service value (Yuan), Q_S is soil conservation (t ha^{-1}), S_j is the content of type j nutrient in soil (%), C_j is the chemical fertilizer conversion coefficient of class j nutrient, P_j is the market price of class j nutrient (Yuan), E_p is the potential erosion modulus of cultivated land (t km^{-2} yr^{-1}), E_R is the actual erosion modulus (t km^{-2} yr^{-1})
		Reducing land abandonment	Opportunity cost method	V_{S2}=P×Q×S/(10000 ×h×d)	V_{S2} is the value of reducing land abandon (Yuan), P is the annual income of farmland (Yuan ha^{-1}), Q is the amount of soil conservation (t ha^{-1}), S is the area of farmland cultivation (ha), h is the thickness of the plough layer of farmland (cm), d is soil bulk density (g cm^{-3})
Cultural service	Social security service	Guaranteeing hidden unemployed farmers	Substitute cost method	V_P=N×M×R	V_P is the social security service value of farmland (Yuan), N is the population which needs to accept the lowest living security in rural areas (capita), M is the lowest living security standard of urban residents per capita (Yuan), R is the ratio of annual consumption expenditure of rural residents per capita to annual consumption expenditure of urban residents per capita
	Entertainment and cultural service	Relaxation and entertainment	Equivalent factor method	$V_T=0.01C_0=\frac{1}{7}\times\left(\sum_{i=1}^{n} m_i \times p_i \times q_i\right)\times\frac{1}{T}$	V_T is the entertainment and cultural service value of farmland (Yuan), C_0 is the food production service value of farmland per hectare (Yuan ha^{-1}), m_i is the area of type i food crop planted (ha), p_i is the price of type i food crop (Yuan kg^{-1}), q_i is the per unit yield of type i food crop (t ha^{-1}), T is the total planting area of food crops (ha)

food production service.

3.2.5 Value of soil conservation service

The brown soil is distributed over the largest area in Qingdao City. The management level of the farmland ecosystem in brown soil areas is high, and the crop coverage rate is also high. The soil attached to crop roots can reduce the soil loss caused by raindrop splashing, wind erosion, surface runoff erosion and other factors (Sun et al., 2013). Therefore, the soil conservation service of the farmland ecosystem can reduce the loss of soil nitrogen, phosphorus, potassium and other elements caused by erosion, maintain soil fertility, reduce the amount of chemical fertilizer applied in farmland,

and reduce the loss of farmland economic benefits caused by soil degradation. The value of the soil conservation service of the farmland ecosystem includes the service values of maintaining soil nutrients and reducing land abandonment, which are estimated by the shadow price method and the opportunity cost method, respectively.

3.2.6 Value of social security service

The farmland ecosystem provides all kinds of agricultural products for human beings, and it is an important guarantee for the farmer's livelihood. The scale of the rural surplus labor force is large, but it is hidden, so it does not directly bring pressure to society that is as great as the urban unemployed population. If the rural surplus labor force does not have enough farmland for basic livelihood security, then the local government needs to pay the minimum level of living security for them. Therefore, we can regard the rural surplus labor force as the population who need to receive the minimum level of living security in rural areas, and according to the annual agricultural employment population in Qingdao City, China's agricultural hidden unemployment rate is 48.6% (Sun et al., 2007). Using the standard of the minimum living security for urban residents in Qingdao City, and the ratio of rural residents' annual consumption expenditure per capita to urban residents' annual consumption expenditure per capita, the value of the social security service of the farmland ecosystem in Qingdao City can be calculated by the substitute cost method. The Civil Affairs Bureau of Qingdao City proposed the average standard of minimum living security for urban residents of Qingdao City in 2017 as 630 Yuan per capita (http://www. qingdao.gov.cn/n172/n24624151/n24625835/n24625849/n24625863/170324140910626625.html).

3.2.7 Value of entertainment and cultural service

In the process of the development of agricultural civilization, farmland not only provides the important means of industries and livelihood for human beings, but also forms diverse agricultural cultures. It provides people with places for leisure, entertainment, tourism and for returning to nature, enjoying pastoral scenery and meeting people's specific aesthetic needs (Ye et al., 2012). In recent years, with the continuous improvement of urban residents' recognition of and participation in leisure agriculture, suburban leisure agriculture has developed rapidly, and the entertainment and cultural service value of the farmland ecosystem has continued to rise higher. At present, the agricultural tourism income of Qingdao City is not counted separately, so the equivalent factor method is used to estimate the entertainment and cultural service value of the farmland ecosystem. The equivalence ratio of the entertainment cultural service value to the provisioning service value of the farmland ecosystem is 0.01:1, so the entertainment cultural service value of the farmland ecosystem per unit area can be obtained by multiplying the equivalent product provisioning service per unit area by 0.01.

4 Results

4.1 Composition of farmland ecosystem service values and their changes

4.1.1 Provisioning service value and its changes

The provisioning service value of the farmland ecosystem in Qingdao City showed an upward trend from 1997 to 2017, and only a slight decrease in 2007. The food producing service values of wheat, corn, peanut, vegetables and fruits accounted for a large portion of the total provisioning service values in the 5 years (Table 2). The provisioning service value is greatly affected by human activities. Optimizing crop planting structure and improving agricultural technology and farmland management are helpful for making full use of farmland productivity and improving the efficiency of agricultural production and the farmland ecosystem services value.

Table 2 Provisioning service values of various crops of the farmland ecosystem in Qingdao City during 1997–2017 ($\times 10^8$ Yuan)

Crop species	1997	2002	2007	2012	2017
Wheat	33.27	20.74	29.03	37.08	31.60
Corn	8.47	11.39	16.92	23.54	22.72
Soybean	1.58	1.66	1.46	1.02	0.36
Potato	2.68	2.75	1.31	0.86	0.58
Peanut	21.73	35.86	34.62	36.99	32.23
Cotton	0.26	0.44	0.55	0.63	0.06
Tobacco	1.89	1.58	0.53	0.43	0.22
Vegetable	102.00	211.83	185.96	198.84	228.51
Fruit	37.03	57.05	62.55	63.53	65.52
Total	208.91	343.30	332.92	362.93	381.81

4.1.2 Values of carbon fixation service and oxygen release service and their changes

Based on the moisture content of various crops, economic coefficients and yearly actual yields per hectare, the total net primary productivities of various crops in Qingdao City in 1997, 2002, 2007, 2012 and 2017 were calculated (Table 3). Using the carbon tax method and afforestation cost method, the carbon fixation service values of the farmland ecosystem of Qingdao City in the 5 years were estimated according to the absorption of 1.63g CO_2 and the release of 1.19 g O_2 when producing 1 gram of dry organic matter by photosynthesis, and the average carbon tax rate and afforestation cost were taken as the carbon fixation costs of the farmland ecosystem. In 1990, the carbon tax rate in Sweden was 150 US dollar t^{-1} C (Ouyang et al., 2004), and the exchange rates of Chinese currency against the US dollar in the 5 years were calculated at 8.20, 8.20, 7.60, 6.30 and 6.80 Yuan to 1 US dollar, respectively (Zhang et al., 2008). The afforestation cost is 260.9 Yuan t^{-1} C (Chen et al., 2012). Be-

Table 3 Net primary productivities of various crops produced by the farmland ecosystem of Qingdao City in the 5 years

Crop	Moisture content (%)	Economic coefficient	Net primary productivity ($\times 10^4$ t yr^{-1})				
			1997	2002	2007	2012	2017
Wheat	12.50	0.37	374.71	256.81	330.05	365.33	298.94
Corn	13.50	0.49	131.20	193.25	264.33	319.65	294.87
Soybean	12.50	0.18	24.02	27.67	22.47	13.64	4.64
Potato	80.00	0.50	4.92	5.54	2.42	1.38	0.90
Peanut	10.00	0.43	64.51	116.73	103.81	96.17	80.30
Cotton	8.30	0.35	0.52	0.98	1.13	1.13	0.11
Tobacco	8.20	0.55	1.34	1.23	0.38	0.27	0.13
Vegetable	82.50	0.90	64.81	148.16	119.73	110.79	122.07
Fruit	77.50	0.70	25.71	43.45	43.90	38.60	38.15
Sum	—	—	691.74	793.83	888.22	946.96	840.10

cause the research period is long and price fluctuations exist, in order to ensure the comparability of prices in different years, the final results were converted to the relative prices of 2017 according to the purchase price index of industrial producers of 336.3, 307.0, 427.5, 546.5 and 527.6 in the 5 years, respectively.

The oxygen release service value of the farmland ecosystem of Qingdao City was evaluated by the industrial oxygen production method and afforestation cost method, with the industrial cost of producing the oxygen of 400 Yuan t^{-1} and the average afforestation cost of 352.93 Yuan t^{-1} released by forest photosynthesis used as oxygen producing costs, respectively. In order to ensure the comparability of prices in different years, with 1985 as the base period, the calculated results of farmland ecosystem service values in the 5 years were translated into relative prices for 2017 based on the producer price index in 1985 for 1997, 2002, 2007, 2012 and 2017, namely 315, 292.6, 353.8, 393.4 and 376.2 Yuan t^{-1}, respectively.

The values of the carbon fixation service and oxygen release service of the farmland ecosystem in Qingdao City increased gradually from 1997 to 2017 (Table 4). Due to the increase of net primary productivity, the value of carbon fixation service increased by 8.38×10^8 Yuan, and the value of oxygen release service increased by 45.39×10^8 Yuan in the period of 1997–2017. In the farmland ecosystem in Qingdao City, the net primary productivities of wheat, corn, peanut, vegetables and fruits are larger than those of other crops, and the values of carbon fixation service and oxygen release service of these crops also account for a large proportion of the total value of farmland ecosystem services.

Table 4 Values of the carbon fixation service and oxygen release service of different crops of the farmland ecosystem in Qingdao City during 1997–2017 ($\times10^8$ Yuan)

Crop	Carbon fixation service value					Oxygen release service value				
	1997	2002	2007	2012	2017	1997	2002	2007	2012	2017
Wheat	15.44	10.28	14.04	15.71	13.12	36.03	22.74	38.04	50.61	39.82
Corn	5.41	7.77	11.24	13.74	12.95	12.62	17.11	30.47	44.28	39.28
Soybean	0.99	1.11	0.96	0.59	0.20	2.31	2.45	2.59	1.89	0.62
Potato	0.20	0.22	0.10	0.06	0.04	0.47	0.49	0.28	0.19	0.12
Peanut	2.66	4.67	4.42	4.13	3.53	6.20	10.34	11.97	13.32	10.70
Cotton	0.02	0.04	0.05	0.05	0.01	0.05	0.09	0.13	0.16	0.01
Tobacco	0.06	0.05	0.02	0.01	0.01	0.13	0.11	0.04	0.04	0.02
Vegetable	2.67	5.93	5.09	4.76	5.36	6.23	13.12	13.80	15.35	16.26
Fruit	1.06	1.74	1.87	1.66	1.68	2.47	3.85	5.06	5.35	5.08
Total	28.50	31.77	37.79	40.71	36.88	66.52	70.29	102.38	131.18	111.91

4.1.3 Value of water conservation service and its changes

Based on the area weighted average of annual precipitation of Qingdao City in 1997, 2002, 2007, 2012 and 2017, the thickness of the farmland soil layer was 22.88 cm, the soil non-capillary porosity was 11.94% (History and Annuals Office of Qingdao, 1997), and the cost of reservoir construction was 0.67 Yuan m^{-3} according to the constant price in 1990. The water conservation service value of the farmland ecosystem of Qingdao City was calculated by the substitute cost method (Table 5). In order to ensure that the costs of reservoir construction in different years were comparable, the fixed asset investment price index in the 5 years (210.3, 222.3, 271.8, 343.9 and 262.4) was used to convert the construction costs of reservoirs into the relative prices of 2017, namely, 1.41, 1.49, 1.82, 2.30 and 1.76 Yuan m^{-3}, respectively. Because the value of the water conservation service of the farmland ecosystem is greatly affected by precipitation, it is higher in years with abundant precipitation and lower in years with less precipitation. In general, the value of the water conservation service shows an increasing trend, and the water conservation service value in 2017 was 1.25 times that in 1997.

Table 5 Water conservation service value of the farmland ecosystem in Qingdao City during 1997–2017

Item	1997	2002	2007	2012	2017
Annual precipitation (mm)	575.27	481.03	1012.46	649.12	674.92
Farmland area ($\times 10^4$ ha)	76.03	77.40	76.31	74.86	70.04
Value of intercepting precipitation by crops ($\times 10^8$ Yuan)	3.08	2.77	7.03	5.59	4.16
Value of maintaining water by soil ($\times 10^8$ Yuan)	2.93	3.15	3.79	4.70	3.37
Value of the water conservation service of farmland ($\times 10^8$ Yuan)	6.01	5.92	10.82	10.29	7.53

Note: Annual precipitation is cited from Qingdao City Statistical Yearbooks of 1998, 2003, 2008, 2013 and 2018.

4.1.4 Value of climate regulating service and its changes

According to the yields of major crops such as wheat, corn, potato and soybean of Qingdao City in the five years and the grain prices in the current year, the value of the food production and provisioning service of the farmland ecosystem per hectare was calculated; that is, the equivalent product provisioning service value was calculated, and then the equivalent climate regulating service value was calculated. The climate regulating service value of the farmland ecosystem was calculated by using the equivalent climate regulating service value and farmland area (Table 6). The climate regulating service value of the farmland ecosystem in Qingdao City increased from 29.35×10^8 to 46.28×10^8 Yuan in the period of 1997–2017.

Table 6 Climate regulatory service value of the farmland ecosystem in Qingdao City during 1997–2017 ($\times 10^4$ Yuan)

Item	1997	2002	2007	2012	2017
Equivalent product provisioning service value	0.43	0.58	0.65	0.77	0.74
Equivalent climate regulating service value	0.39	0.52	0.58	0.69	0.66
Climate regulating service value	29.35	39.99	44.27	51.61	46.28

4.1.5 Value of soil conservation service and its changes

The potential erosion modulus of cultivated land is 7060.42 t km^{-2} yr^{-1}, and the actual erosion modulus is 335.37 t km^{-2} yr^{-1} in Qingdao City (Zhao, 2017). The annual land income is expressed as the agricultural added value per hectare in Qingdao City, and the nutrient contents of N, P and K of soil are 0.054%, 0.020% and 1.045%, respectively. According to the evaluation specification of forest ecosystem services issued by the former State Forestry Administration of China in 2008 (LY/T 1721–2008), N and P are mainly obtained from the chemical fertilizer diammonium phosphate, and K is mainly obtained from the chemical fertilizer potassium chloride. The price of diammonium phosphate is 2400 Yuan t^{-1}, with N and P contents accounting for 14% and 15%, respectively, while the price of potassium chloride is 2200 Yuan t^{-1}, with K content accounting for 50%. Based on these contents of N and P in diammonium phosphate and K in potassium chloride, the chemical fertilizer conversion coefficients for N, P and K are 7.14, 6.67 and 5.46, respectively. To meet the requirement of a comparable price in different years, with 1997 as the base period, the prices of chemical fertilizer in the 5 years were converted to the relative price of 2017 by using the price index of agricultural means of production in the corresponding year, i.e., 100.00, 80.78, 108.09, 158.84 and 145.49. Then the soil conservation service value of the farmland ecosystem in Qingdao City was calculated (Table 7). The values of the reducing land abandonment service and the maintaining soil nutrients service of the farmland ecosystem in Qingdao City increased from 1997 to 2017, and the value of the maintaining soil nutrients service accounted for a large proportion of the value of the soil conservation service.

Table 7 Soil conservation service value of the farmland ecosystem in Qingdao City during 1997–2017 ($\times 10^8$ Yuan)

Item	1997	2002	2007	2012	2017
Value of maintaining soil nutrients	70.65	65.54	70.15	78.45	77.53
Value of reducing land abandonment	1.57	2.41	3.22	3.50	4.04
Value of soil conservation service	72.23	67.95	73.37	81.95	81.57

4.1.6 Value of social security service and its changes

According to the population in the rural area which needs to receive the minimum social security, the annual consumption expenditure of rural residents per capita, the annual consumption expenditure of urban residents per capita and other relevant factors, the value of the social security services of the farmland ecosystem in Qingdao City was calculated by the substitute cost method (Table 8). The relevant data were collected from Qingdao City Statistical Yearbooks of 1998, 2003, 2008, 2013 and 2018 and Statistical Bulletin of National Economic and Social Development of Qingdao City in 1997, 2002, 2007, 2012 and 2017, and other sources. The results show that the social security service value of the farmland ecosystem in Qingdao City has a fluctuating and declining trend in general, due to the continuously improving rural employment and the decrease of the population which needed to utilize social security.

Table 8 Social security service value of the farmland ecosystem in Qingdao City during 1997–2017

Item	1997	2002	2007	2012	2017
Rural population in Qingdao City ($\times 10^4$ people)	155.20	121.38	102.30	104.95	101.86
Population needing to receive minimum social security ($\times 10^4$ people)	72.63	56.81	47.88	49.12	47.67
Annual consumption expenditure of rural residents per capita (Yuan)	2150	2820	4736	8653	12928
Annual consumption expenditure of urban residents per capita (Yuan)	5525	7344	13376	20391	30569
Annual consumption expenditure of rural residents per capita to that of urban residents	0.39	0.38	0.35	0.42	0.42
Social security service value ($\times 10^8$ Yuan)	21.37	16.49	12.82	15.76	15.24

4.1.7 Value of the entertainment and cultural service and its changes

The value of the entertainment and cultural service of the farmland ecosystem in Qingdao City was estimated by the equivalent factor method, using the value equivalence ratio of entertainment and cultural service to food production service (product provisioning service) of the farmland ecosystem as 0.01:1. The economic value of the food production service per unit area was multiplied by 0.01 to obtain the value equivalent of the entertainment and cultural service of the farmland ecosystem (Table 9) in Qingdao City, which was fluctuating and increasing from 1997 to 2017, with the value in 2017 being 1.58 times of that in 1997. With the income improvement and the change of living concept, people gradually realized the value of the entertainment and cultural service of farmland, and are more willing to experience the use of the farmland ecosystem to carry out leisure tourism, entertainment and cultural activities.

Table 9 Value and change of the entertainment and cultural service of the farmland ecosystem in Qingdao City during 1997–2017

Item	1997	2002	2007	2012	2017
Value equivalent of the food production service ($\times 10^4$ Yuan ha^{-1})	0.43	0.58	0.65	0.77	0.74
Value equivalent of the entertainment and cultural service (Yuan ha^{-1})	43.38	58.06	65.18	77.45	74.24
Value of the entertainment and cultural service ($\times 10^4$ Yuan)	3298.16	4493.70	4973.97	5798.53	5199.81

4.2 Comprehensive analysis on the farmland ecosystem services value of Qingdao City

In the farmland ecosystem service value of Qingdao City, the value of the product provisioning service accounted for the largest proportion of the total, followed by the regulating service value, the cultural service value and the supporting service value. Generally, the proportions of the values of different services to the total were relatively stable during the period of 1997–2017; although the proportions of the values of different services to the total farmland service value were significantly different. In the 5 years which we analyzed, the combined proportions of the values of product provisioning, carbon fixation, oxygen release, and soil conservation services to the total farmland ecosystem service value was higher than 85%. The proportion of the product provisioning service value to the total was the largest and showed an increasing trend with fluctuation, indicating that the product provisioning of crops, especially those of grains, are the main farmland ecosystem service of Qingdao City. From largest to smallest, the values of farmland ecosystem services in Qingdao City are: the product provisioning service, the carbon fixation and oxygen release service, the soil conservation service, the climate regulating service, the social security service, the water conservation service, and the entertainment and cultural service (Table 10).

In the period of 1997–2017, the total value of farmland ecosystem services in Qingdao City increased from 499.74×10^8 to 681.74×10^8 Yuan, and basically showed a steady increasing trend. Meanwhile, the value of the ecosystem services per hectare also increased, from 6.57×10^4 in 1997 to 9.73×10^4 Yuan ha^{-1} in 2017 (Fig. 2).

From 1997 to 2017, the farmland acreage decreased from 76.03×10^4 ha to 70.04×10^4 ha. Meanwhile, the value of direct services of the farmland ecosystem (i.e. the product provisioning service), as well as the value of indi-

Table 10 Composition of the values of farmland ecosystem services in Qingdao City during 1997–2017 (×10^8 Yuan)

Item	1997		2002		2007		2012		2017	
	Value	Ratio (%)	Value	Ratio (%)	Value	Ratio (%)	Value	Ratio (%)	Value	Ratio (%)
Product provisioning service	208.91	41.85	343.30	59.58	332.92	54.14	362.93	52.22	381.81	56.01
Carbon fixation and oxygen release service	161.54	32.32	102.06	17.71	140.17	22.80	171.89	24.73	148.79	21.83
Water conservation service	6.01	1.20	5.92	1.03	10.82	1.76	10.29	1.48	7.53	1.10
Climate regulating service	29.35	5.87	39.99	6.94	44.27	7.20	51.61	7.43	46.28	6.79
Soil conservation service	72.23	14.45	67.95	11.79	73.37	11.93	81.95	11.79	81.57	11.96
Social security service	21.37	4.28	16.49	2.86	12.82	2.08	15.76	2.27	15.24	2.24
Entertainment and cultural service	0.33	0.07	0.45	0.08	0.50	0.08	0.58	0.08	0.52	0.08
Total	499.74	100	576.16	100	614.87	100	695.01	100	681.74	100

rect services (which include the regulating service, the supporting service and the cultural service) of the farmland ecosystem in Qingdao City, both showed upward trends, and the ratios of the values of indirect to direct services were 1.39, 0.68, 0.85, 0.91 and 0.79, respectively, showing an overall downward trend (Fig. 3). These changes were mainly caused by the rise of agricultural product prices and the optimizing of crop planting structure. The results show that with the continuous improvement of farming technology and field management technology, the agricultural production efficiency in Qingdao City continued to improve.

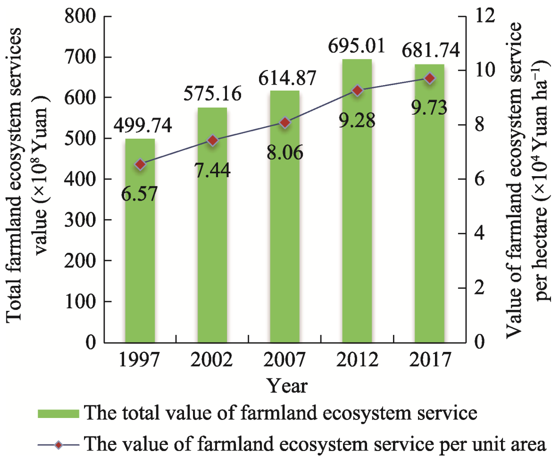

Fig. 2 The total value and the value per unit area of farmland ecosystem services in Qingdao City and their changes during 1997–2017

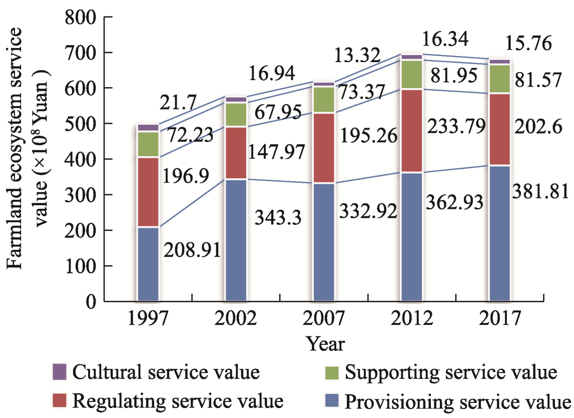

Fig. 3 The composition of the values of farmland ecosystem services in Qingdao City and their changes

5 Discussion

The proportions of provisioning service value, regulating service value, supporting service value and cultural service value to the total farmland ecosystem value in Qingdao City are in descending order, which is similar to those of Huailai County, Hebei Province in 2012 (Zhang et al., 2016) and Beidaihe District, Hebei Province in 2014 (Liu et al., 2017). However, the proportion of entertainment and cultural service value to the total farmland ecosystem service value in Qingdao City is lower than that of Huailai County (Zhang et al., 2016). The values of farmland ecosystem services per hectare in Qingdao City are higher than those of Wuma River watershed in Guizhou Province (Wu et al., 2016) and the average standard value for China in 2003 (Sun et al, 2007).

The importance of the indirect services value of the farmland ecosystem should be well recognized, so farmland should be reasonably utilized and effectively protected. Agricultural production should be developed reasonably based on the natural conditions of different regions, and agricultural production efficiency should be continuously improved by adopting scientific planting technology and efficient management to ensure the quality of agricultural products. We should promote supply-side structural reform in agriculture, make full use of the indirect service value of the farmland ecosystem (such as supporting service value and cultural service value), speed up the construction of modern agricultural parks, and develop ecological leisure agriculture and agricultural eco-tourism, thereby achieving the goal of providing maximum welfare for the human population through the farmland ecosystem.

In evaluating the values of the climate regulating service and the entertainment and cultural service of the farmland ecosystem in Qingdao City, only the positive service value of the farmland ecosystem was considered, and the loss of value caused by unreasonable agricultural activities, such as excessive fertilization, was ignored. Therefore, the actual value of the farmland ecosystem services should be slightly less than that reported in this paper, and that discrepancy should be further analyzed and discussed in the future research.

6 Conclusions

The farmland ecosystem provides the direct service of supplying agricultural products, indirect services of regulating service, supporting service and cultural service, and the service values of agricultural product provisioning, carbon fixation and oxygen release, water conservation, climate regulation, soil conservation, social security service, entertainment and cultural service, etc. Various methods (market value method, carbon tax method, afforestation cost method, industrial oxygen production method, substitute cost method, opportunity cost method and equivalent factor method) were used to evaluate the values of the farmland ecosystem services in Qingdao City in 1997, 2002, 2007, 2012 and 2017. The total value of the farmland ecosystem services in Qingdao City increased from 499.74×10^8 to 681.74×10^8 Yuan between 1997 and 2017, and the value of ecosystem services per hectare increased from 6.57×10^4 to 9.73×10^4 Yuan ha^{-1}. The service values of product provisioning, carbon fixation and oxygen release, and soil conservation of the farmland ecosystem in Qingdao City accounted for the largest portion of the total ecosystem services value, which showed an upward trend, and they were the main farmland ecosystem services in Qingdao City. The supporting service value and the cultural service value of the farmland ecosystem in Qingdao City were low, but they still have great utilization potential.

References

Bai Y, Ouyang Z Y, Zheng H, et al. 2010. Environmental benefit-loss analysis of agro-ecosystem in Haihe River basin, China. *Chinese Journal of Applied Ecology*, 21(11): 2938–2945. (in Chinese)

Carpenter S R, DeFries R, Dietz T M, et al. 2006. Millennium ecosystem assessment: Research needs. *Science*, 314(5797): 257–258.

Chen Z Z, Zhang Y Q, Wu B, et al. 2012. Evaluation of ecosystem services function value of farmland shelterbelts in Shandong Province. *Chinese Journal of Ecology*, 31(1): 59–65. (in Chinese)

Costanza R, d'Arge R, de Groot R, et al. 1997. The value of ecosystem services and natural capital. *Nature*, 387(6630): 253–260.

Costanza R, de Groot R, Sutton P, et al. 2014. Changes in the global value of ecosystem services. *Global Environmental Change*, 26: 152–158.

Du J Q, Wang J S, Teng Y G, et al. 2008. Dynamic evaluation on ecosystem service value of Chongqing City. *Chinese Journal of Ecology*, 27(7): 1187–1192. (in Chinese)

Alejandre E M, van Bodegom P M, Guinee J B. 2019. Towards an optimal coverage of ecosystem services in LCA. *Journal of Cleaner Production*, 231: 714–722.

History and Annuals Office of Qingdao. 1997. History and annuals of Qingdao—Physical geography/meteorology annuals. Beijing: Xinhua Press. (in Chinese)

Lin E D, Guo L P, Ju H. 2018. Challenges to increasing the soil carbon pool of agro-ecosystems in China. *Journal of Integrative Agriculture*, 17(4): 723–725.

Liu L H, Yin C B, Qian X P. 2015. Calculation methods of paddy ecosystem service value and application: A case study of Suzhou City. *Progress in Geography*, 34(1): 92–99. (in Chinese)

Liu X Z, Zhao Z B, Li K G. 2017. Measurement of farmland ecosystem services evaluation in Beidaihe District, Hebei Province, China. *Journal of Agricultural Resources and Environment*, 34(4): 390–396. (in Chinese)

Luo Q L, Luo Y L, Zhou Q F, et al. 2019. Does China's Yangtze River Economic Belt policy impact on local ecosystem services? *Science of the Total Environment*, 676: 231–241.

Lu Z B, Dong D F, Yang B, et al. 2016. Effects of crop species richness on the community of soil nematodes in an experimental agro-ecosystem. *European Journal of Soil Biology*, 73: 26–33.

Marinidou E, Jimenez-Ferrer G, Soto-Pinto L, et al. 2019. Agro-ecosystem services assessment of silvopastoral experiences in Chiapas, Mexico: Towards a methodological proposal. *Experimental Agriculture*, 55(1): 21–37.

Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: A framework for assessment. Washington D C, USA: Island Press.

Narducci J, Quintas-Soriano C, Castro A, et al. 2019. Implications of urban growth and farmland loss for ecosystem services in the western United States. *Land Use Policy*, 86: 1–11.

Ouyang Z Y, Zhao T Q, Zhao J Z, et al. 2004. Ecological regulation services of Hainan Island ecosystem and their valuation. *Chinese Journal of Applied Ecology*, 15(8): l395–l402. (in Chinese)

Parkes M. 2006. Personal commentaries on "Ecosystems and human well-being: Health synthesis—A report of the Millennium Ecosystem Assessment". *Ecohealth*, 3(3): 136–140.

Porter J, Costanza R, Sandhu H, et al. 2009. The value of producing food, energy, and ecosystem services within an agro-ecosystem. *Ambio*, 38(4): 186–193.

Sil A, Fernandes P M, Rodrigues A P, et al. 2019. Farmland abandonment decreases the fire regulation capacity and the fire protection ecosystem service in mountain landscapes. *Ecosystem Services*, 36: 100908. DOI：10.1016/j.ecoser.2019.100908.

Simpson R D. 2019. Conservation incentives from an ecosystem service: How much farmland might be devoted to native pollinators? *Environmental & Resource Economics*, 73(2): 661–678.

Sun X Z, Zhou H L, Xie G D. 2007. Ecological services and their values of Chinese agroecosystem. *China Population*, *Resources and Environment*, 17(4): 55–60. (in Chinese)

Sun Y, Eerdun H, Du H S. 2013. Application of vegetation cover in soil erosion modulus calculation. *Bulletin of Soil and Water Conservation*, 33(5): 185–189. (in Chinese)

Tzilivakis J, Warner D J, Holland J M. 2019. Developing practical techniques for quantitative assessment of ecosystem services on farmland. *Ecological Indicators*, 106: 105514. DOI:10.1016/j.ecolind.2019. 105514.

van den Belt M, Blake D. 2014. Ecosystem services in New Zealand agro-ecosystems: A literature review. *Ecosystem Services*, 9: 115–132.

Wu S Q, Lei J C, Wang J M, et al. 2017. Evaluation on farmland ecosystem service value in Wuma River watershed. *Guizhou Agricultural Sciences*, 45(10): 151–155. (in Chinese)

Xie G D, Lu C X, Leng Y F, et al. 2003. Ecological assets valuation of the Tibetan Plateau. *Journal of Natural Resources*, 18(2): 189–196. (in Chinese)

Xie G D, Xiao Y. 2013. Review of agro-ecosystem services and their values. *Chinese Journal of Eco-Agriculture*, 2l(6): 645–651. (in Chinese)

Xie G D, Xiao Y, Zhen L, et al. 2005. Study on ecosystem services value of food production in China. *Chinese Journal of Eco-Agriculture*, 13(3): 10–13. (in Chinese)

Yan H M, Liu J Y, Cao M K. 2007. Spatial pattern and topographic control of China's agricultural productivity variability. *Acta Geographica Sinica*, 62(2): 171–180. (in Chinese)

Yang Z X, Zheng D W, Wen H. 2005. Studies on service value evaluation of agricultural ecosystem in Beijing region. *Journal of Natural Resources*, 20(4): 564–571. (in Chinese)

Ye Y Q, Zhang J E, Qin Z, et al. 2012. Ecological benefit-loss analysis of agricultural ecosystem in Foshan City, China. *Acta Ecologica Sinica*, 32(14): 4594–4604. (in Chinese)

Yin F, Mao R Z, Fu B J, et al. 2006. Farmland ecosystem service and its formation mechanism. *Chinese Journal of Applied Ecology*, 17(5): 929–934. (in Chinese)

Zhang C G, Qiu L. 2018. Comprehensive sustainability assessment of a biogas-linked agro-ecosystem: A case study in China. *Clean Technologies and Environmental Policy*, 20(8): 1847–1860.

Zhang D, Li X S, Chen Y H. 2016. Classification evaluation on agriculture ecosystem service value of Huailai County. *Research of Soil and Water Conservation*, 23(1): 234–239. (in Chinese)

Zhang X L, Ye S Y, Yin P, et al. 2008. Ecosystem services value and its temporal change of coastal wetlands in southern Laizhou Bay. *Chinese Journal of Ecology*, 27(12): 2195–2202. (in Chinese)

Zhang H F, Ouyang Z Y, Zheng H, et al. 2009. Evaluation of agricultural ecosystem services value in Manas River watershed of China. *Chinese Journal of Eco-Agriculture*, 17(6): 1259–1264. (in Chinese)

Zhao H. 2017. Research on risk assessment of soil and water loss in Qingdao based on RS and GIS. Ms. thesis, Jinan, China: Shandong Normal University. (in Chinese)

青岛市农田生态系统服务价值及变化

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摘 要：农田生态系统服务价值由供给服务价值、调节服务价值、支持服务价值和文化服务价值构成，充分认识农田生态系统服务价值对于农业发展与农田保护有重要指导意义。在构建农田生态系统服务价值评估指标体系基础上，利用市场价值法、碳税法、造林成本法、替代成本法、当量因子法等方法，评估了 1997、2002、2007、2012 和 2017 年青岛市农田生态系统服务价值。评估结果表明：1997–2017 年青岛市农田生态系统总服务价值由 499.74×10^8 元增加到 681.74×10^8 元，单位面积农田生态系统服务价值由 6.57×10^4 元/公顷增加到 9.73×10^4 元/公顷。农田的产品供给服务、固碳释氧服务和土壤保持服务是青岛市农田生态系统服务的主要方式，产品供给服务价值、固碳释氧服务价值和土壤保持服务价值占青岛市农田生态系统服务总价值的比重大且呈上升趋势。提出了保护和合理利用农田、因地制宜发展农业生产、提高农业生产效率、加快现代农业园区建设、推进农业供给侧的结构性改革，以及发展生态休闲农业、农业生态旅游等充分利用农田生态系统的间接服务价值，为市民提供最大化福利的青岛市农业发展措施。

关键词：青岛市；农田；生态系统服务价值；评估