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ANALYSIS OF ECOLOGICAL FOOTPRINT PRESSURE AND AGRICULTURAL GRAIN CONSUMPTION EFFICIENCY

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Abstract

Agriculture, throughout the world and history, has been the basic industry. To probe the effect of consuming agricultural grain on the ecological footprint in Taiwan, this study analyzed the data of agricultural grain consumed from 2007 to 2016. The results demonstrated that the ecological footprint of agricultural grain consumed increased by 1.02-fold between 2007 and 2016, and the average ecological footprint of agricultural grain consumption was 0.1783 ha per capita. In addition, the carrying arable land area was 0.0347 ha per capita, and it reduced by 1.1-fold. However, the ratio of agricultural grain ecological footprint to the arable land area increased by 1.3-fold. Compared with over 1.2-fold with Taiwan's land area between 2007 and 2016. Thus, the ecological footprint of agricultural grain consumption has made it impossible for all of Taiwan to carry it out. However, ecological stress and intensity also exhibit the efficiency of agricultural grain consumption and have reduced gradually since 2013, and the economic value per unit area has reduced continuously.

Keywords: Agricultural grain consumed, Ecological footprint, Ecological Pressure, Ecological stress, Ecological intensity.

Introduction

According to an estimate from the United Nations, the world's population will continue to grow and will increase to 8.5 billion by 2030, 9.7 billion by 2050, and 11.2 billion by 2100 (Aydin et al., 2019). However, the world's resources are limited, and the ecological footprint (EF) of human consumption has exceeded the production capacity of the earth since the 1980s. In addition, rapid world economic growth (3%–4% per year) has resulted in a significantly unequal distribution of resources and constitutes a menace to the environmental ecology of the earth; the speed of human's transformation of resources into waste has exceeded the speed of transformation of waste into resources by nature (Bogoni et al., 2018). Therefore, how to use environmental resources effectively, reduce the waste produced, and implement sustainable development of environmental ecology have become urgent global concerns.

Agriculture, throughout the world and history, has been the basic industry and plays a critical role in the food supply and social stability (Zhan et al., 2019). During the process of industrialization in Taiwan, development of industry and information technology has promoted its economic growth (Dai et al. 2017). Notably, the value of agricultural output has declined relatively gradually. According to statistical data from 2011, land production type (primary industry) accounts for merely 0.91% of gross domestic product (GDP) in Taiwan (Lin et al., 2017). Although agriculture has not been a critical economic industry, it is closely related to public livelihood and Taiwanese residents' food security. Therefore, under the premise of sustainable development, how to balance industrial development and environmental protection is a goal that every country should pursue as a priority.

EF analysis can investigate this topic directly and provides a means to compare the production of the ecosystem and consumption of the economy to demonstrate whether space is available for economic expansion in the context of ecological sustainability, or whether the industrial society has overdrawn the local (or global) tolerance. Briefly, EF analysis helps confirm ecological constraints that society should pay attention to when formulating policies to avoid or reduce overconsumption and achieve the goal of sustainability (Lee, 1999).

Therefore, this study used the data of agricultural grain consumption of Taiwan from 2007 to 2016 to conduct calculations and analyses to explore the extent of the impact of agricultural grain consumption on Taiwan's overall EF.

Literature Review

Definition of EF

The concept of EF is simple, but the coverage is quite extensive. It illustrates the circulation of energy and matter needed for the functioning of various economies, and transforms it into the land and water area that the natural world provides in relation to maintaining these flows. This analytical and educational technology can be used not only to assess the sustainability of current human activities, but also to build consensus and assist decision-making.

An EF is based on the biological productivity of land to evaluate the area of resource consumption and waste absorption of a specific population or economy (De Bortoli et al., 2019). That is, as any material or resource is consumed, land must be made available from one or more ecosystems that provide these resources or waste decomposition functions associated with these consumptions (Wackernagel & Rees, 1996). Thus, the size of the EF is directly proportional to the environmental impact; the larger the footprint, the greater the environmental impact (Destek & Sarkodie, 2019).

The size of the footprint is inversely proportional to the biological productivity of the land area available to each person: the larger the footprint, the smaller the biological productivity of the land area available to each individual (Dong et al., 2019).

The focus of the EF is not to emphasize "how bad things are." It is to explore how human beings continue to rely on nature and what they can do to protect the earth's tolerance and support the future of humanity. Understanding ecological constraints can make our sustainability strategy more effective and valuable. EF analysis can help us make wise choices, a choice based on nature. Since each material consumption and waste production needs to be covered by a specific land or water area, the total land area required for population consumption or disposal of waste in a particular area represents the load generated by these populations. In other words, if we compare the economy to "industrial metabolism." On the other hand, the rapid development of progress makes the average per person consumption rate faster than population growth. From this trend, human beings, like other species, need to rely on the supply of nature in their basic needs and needs. Despite the extraordinary achievements in technology and economy, the substances produced by human consumption behavior will return to the biosphere in the form of waste.

The Living Plant Report has been published by the World Wildlife Fund every 2 years and mainly evaluates the consumption of natural resources by using the EF method (Genta et al., 2019) . The International Institute for Management Development, Switzerland, uses EF analysis as an evaluation indicator of environmental infrastructure competitiveness (Ghosh & Chakma, 2018). The Yale Center for Environmental Law & Policy in collaboration with units such as the Global Environmental Sustainability Index published annually by the Research Center of the European Commission has propelled the EF to become a basis for evaluation (Lee et al., 2007). Because sustainability and nonsustainability were the conditions present in the interaction between human socioeconomics and ecosystems, they can present the effect of society’s economic consumption and production activities to stipulate a degree of biological productivity and supply biological productivity through the analysis of the EF time sequence (Lee，2009).

EF Analysis

A complete EF analysis includes the direct use of land area and the indirect impact of all material and energy consumption. The ecological footprint includes not only the natural capital area needed to manufacture renewable resources and life-sustaining services, but also the ecological land area where biological productivity is lost due to factors such as pollution and radiation. Footprints are calculated using enumeration patterns based on limited consumption items and consumption statistics. Therefore, each additional assessment item has the potential to increase the value of the existing EF.

The calculation of the ecological footprint is based on two simple facts: 1. We can retain most of the consumed resources and most of the waste generated; 2. Most of these resources and waste can be converted into these functions. Biological productive land. The way the ecological footprint is calculated clearly indicates how much natural resources a country or region uses. However, these footprints are not a continuous land. Due to the relationship between international trades, the land and water areas used by people are scattered all over the world, which requires a lot of research to determine its location.

EF analysis is the calculation that at a specific time point, the dependence level of society's consumption behavior and standards regarding natural resources and self-purification become notable (Haider & Akram, 2019) . Notably, sustainability and nonsustainability were the conditions present in the interaction between socioeconomics and ecosystems (Li et al., 2019). Thus, the effect could occur that society's economic consumption and production activities demand a degree of biological productivity and supply biological productivity, and this degree could be determined through the analysis of the EF time sequence (Lee， 2009).

This study referred to Du and Lin (2008), who suggested that a complete EF analysis should include the land area directly used and the indirect use that concerns energy consumption. Notably, the footprint is calculated by enumeration, which probably increases the total value of the footprint for each additional evaluation item (Peng et al., 2019). Therefore, the footprint size we calculated was more conservative than the real-world resource use. Theoretically, the EF analysis would calculate the land and water area that all consumption and waste disposal demanded. The calculation process was complex and difficult (Ortegon & Acosta, 2019) ; therefore, we used a simplified method for calculations as follows:

1. We assumed that the lands provided for industry to harvest are sustainable; however, the rate of land decline is often greater than the rate of regeneration.

2. We only subsumed the misappropriation of human direct and indirect activities to natural functions.

3. We only estimated the EF that occupied a larger area if more than two services were provided simultaneously on the same land.

4. We simplified the classification method of the biological productivity for the calculation and analysis.

EF Calculation

Analysis and calculation of the EF method comprised two processes. First, we tracked and analyzed all the resources consumed and all the waste produced. Second, we converted the resources and waste that be consumed into the biological productivity of the land area required to supply and maintain its functions (Pan et al., 2019).

The calculation of the EF includes the following steps. First, we calculated the per capita average consumption of each major consumer item (ci). For a given item, the total consumption value of a region or country (production + import–export) was divided by the population to calculate capita average annual consumption (Xiong & Li, 2019).

Next, we converted each major consumption item into the land area (aai). The method used was based on the per capita average annual consumption (ci; tons per person) divided by average annual productivity of land (p; tons per hectare):

$$aai = ci/p$$

Thus, we summed the total ecological area of consumer goods and services per capita per year up, which is the average total EF per capita (ef).

$$ef = \sum_{i=1}^{n} aai$$

Finally, we calculated the total EF. We averaged total ecological footprint per capita (ef) multiplied by the number of population (N) to determine the EF of a particular region: EF ＝ N × ef

Analysis Of The Value Of Agricultural Grain Consumption Footprint

Value of agricultural grain consumption footprint (VAGCF) is the economic value that represents the production by the EF of per unit agricultural grain consumption, defined as the ratio of per capita GDP to the EF of per capita agricultural food consumption (Yang & Yang, 2019). Through VAGCF analysis, Taiwan's economy, agricultural grain consumption, and ecological environment development can be quantified and then the developing trend explored (Yang & Li., 2019). High VAGCF means satisfactory economic development and a higher output value of per unit land area. High VAGCF also means that the per unit footprint of agricultural grain can create a higher economic value (Yang & Meng, 2019)

Per Capita GDP/Per Capita Agricultural Grain Consumption Footprint = VAGCF

The stress of agricultural grain consumption footprint refers to the pressure on the natural ecological environment caused by the consumption of agricultural grain. Defined as the ratio of total EF (hm2) to the arable land area, and evaluated as the stress of consumption of agricultural grain on arable land in Taiwan (Yilanci et al., 2019)

Results And Discussions

The Result Of The Calculation Of Agricultural Grain Consumption In Taiwan

In this study, according to the data from 2007 to 2016 of the Agricultural Committee of the Executive Yuan, we divided into four categories of agricultural grain crops, namely, rice, miscellaneous grains, vegetables, and fruits; among them, sweet potato had a high yield per unit and no data for imports and exports. Thus, sweet potato was counted individually and not included in miscellaneous grains.

Amount Of Per Capita Agricultural Grain Consumption

According to the statistical data, we used the integration of production volume, import volume, and export volume that correlate with rice, miscellaneous grains, sweet potato, vegetables, and fruits to calculate total consumption and then divided by the population of the current year to calculate the per capita average annual consumption. The result is presented in Table 1. The per capita average annual consumption from highest to lowest over the years was as follows: miscellaneous grains, 0.44 tons/person; fruit, 0.136 tons/person; vegetables, 0.134 tons/person; rice, 0.062 tons/person; and sweet potato, 0.009 tons/person. Among them, miscellaneous grains were imported in the greatest quantity, which explains the recent trend of consuming noodles as the foremost dietary staple.

Table 1. Per capita average annual consumption of various crops in Taiwan (2007–2016)

ears	population	rice	miscellaneous grains	Sweet potato	vegetables	fruits
2007	22958360	0.053	0.448	0.009	0.115	0.142
2008	23037031	0.054	0.408	0.009	0.114	0.139
2009	23119772	0.059	0.448	0.010	0.115	0.131
2010	23162123	0.058	0.462	0.009	0.116	0.141
2011	23224912	0.063	0.434	0.009	0.119	0.146
2012	23315822	0.064	0.441	0.009	0.115	0.140
2013	23373517	0.060	0.409	0.009	0.116	0.138
2014	23433753	0.064	0.427	0.010	0.118	0.140
2015	23492074	0.056	0.442	0.010	0.114	0.135
2016	23539816	0.056	0.427	0.010	0.122	0.128
average	22567530	0.062	0.440	0.009	0.132	0.136

Note: compiled by this study (unit: ha/person)

Consumption Item Converts To Land Area

We divided the total yield of rice, miscellaneous grains, sweet potato, vegetables, and fruits by the arable area to assess the yield of per unit area (Table 2). Generally, the larger the EF, the lower the yield of per unit area, whereas the smaller the EF, the higher the yield per unit area.

Table 2. Yield of per unit area of staple crops in Taiwan (2007–2016)

years	The average of add up	rice	miscellaneous grains	Sweet potato	vegetable	fruits
2007	11.609	4.222	3.180	20.784	17.048	12.810
2008	11.680	4.669	3.186	20.761	17.221	12.563
2009	11.986	5.014	3.344	21.424	17.800	12.350
2010	12.361	4.789	3.130	21.846	18.249	13.793
2011	13.072	5.300	3.094	22.652	19.602	14.713
2012	12.882	5.247	2.894	23.066	18.853	14.352
2013	12.644	4.721	2.893	22.270	18.819	14.514
2014	13.098	5.163	2.899	23.190	19.293	14.946
2015	12.865	5.004	2.927	23.477	18.660	14.256
2016	12.164	4.616	2.583	22.893	18.025	12.700
average	12.436	4.875	3.013	22.236	18.357	13.700

Note: compiled by this study (unit: ha/person)

EF Of Per Capita Agricultural Grain Consumption

According to the analysis of the EF of agricultural grain crop consumed from 2007 to 2016, the result was a slight increase per year, and the EF had the highest with 0.1946 ha/person by 2016, followed by 0.1810 ha/person at 2012; the average was 0.1738 ha/person (Table 3). From 2007 to 2016 in Taiwan, miscellaneous grains was the highest consumption per capita among various crops, and the variation of total EF per capita occurred simultaneously with the variation of the consumption of miscellaneous grains. Therefore, the result indicates that the variation of the EF of agricultural grain crop consumption in Taiwan during the period was mainly affected by the expansion of the EF of miscellaneous grains.

Table 3. Staple crops' EF of per capita consumption in Taiwan (2007–2016)

Year	Sum Of Footprints	Rice	Miscellaneous Grains	Sweet Potato	Vegetable	Fruits
2007	0.1716	0.0124	0.1409	0.0004	0.0067	0.0111
2008	0.1577	0.0115	0.1281	0.0004	0.0066	0.0110
2009	0.1634	0.0118	0.1341	0.0005	0.0064	0.0106
2010	0.1768	0.0121	0.1477	0.0004	0.0064	0.0102
2011	0.1686	0.0119	0.1403	0.0004	0.0061	0.0099
2012	0.1810	0.0123	0.1525	0.0004	0.0061	0.0097
2013	0.1702	0.0126	0.1415	0.0004	0.0062	0.0095
2014	0.1756	0.0124	0.1473	0.0004	0.0061	0.0094
2015	0.1783	0.0112	0.1511	0.0004	0.0061	0.0095
2016	0.1946	0.0121	0.1652	0.0004	0.0068	0.0101
average	0.1738	0.0120	0.1449	0.0004	0.0063	0.0101

Note: compiled by this study (unit: ha/person)

EF Of Total Agricultural Grain Consumption

In Table 4, the average of the total EF was 4,044,082 ha, which was 5.01-fold of the arable area and 1.12-fold of all Taiwan's land, including slope land, building land, arable land, forest, and fossil energy land. Only being engaged in basic agriculture has exhausted the environmental carrying capacity of Taiwan. The consumption of agricultural grain from 2007 to 2016 was more severely overused.

Table 4. Total EFs of consumption of staple crops in Taiwan (2007–2016)

year	population (person)	Arable area (hectare)	The area of Taiwan (hectare)	Ecological footprint per capita (hectare/person)	Total ecological footprint (hectare/year)
2007	22958360	825947	3600000	0.1716	3,939,312
2008	23037031	822364	3600000	0.1577	3,632,419
2009	23119772	815462	3600000	0.1634	3,778,753

2010	23162123	813126	3600000	0.1768	4,094,915
2011	23224912	808294	3600000	0.1686	3,914,584
2012	23315822	802876	3600000	0.1810	4,220,135
2013	23373517	799830	3600000	0.1702	3,977,938
2014	23433753	799611	3600000	0.1756	4,114,269
2015	23492074	796618	3600000	0.1783	4,188,457
2016	23539816	794003	3600000	0.1946	4,580,034
average	23265718	807813	3600000	0.1738	4,044,082

Note: compiled by this study (unit: hectare/year)

Output Value Analysis Of The EF Of Agricultural Grain Consumption In Taiwan

Regarding VAGCF (Figure 1), the trend was unstable from 2009 to 2012 and increased to 128,774 US$/hm2 in 2013, which was the maximum; then, starting in 2014, it began to decrease continuously until 2016 (115,797 US$/hm2). Thus, the output value per unit of agricultural grain crops decreased by a narrow margin.

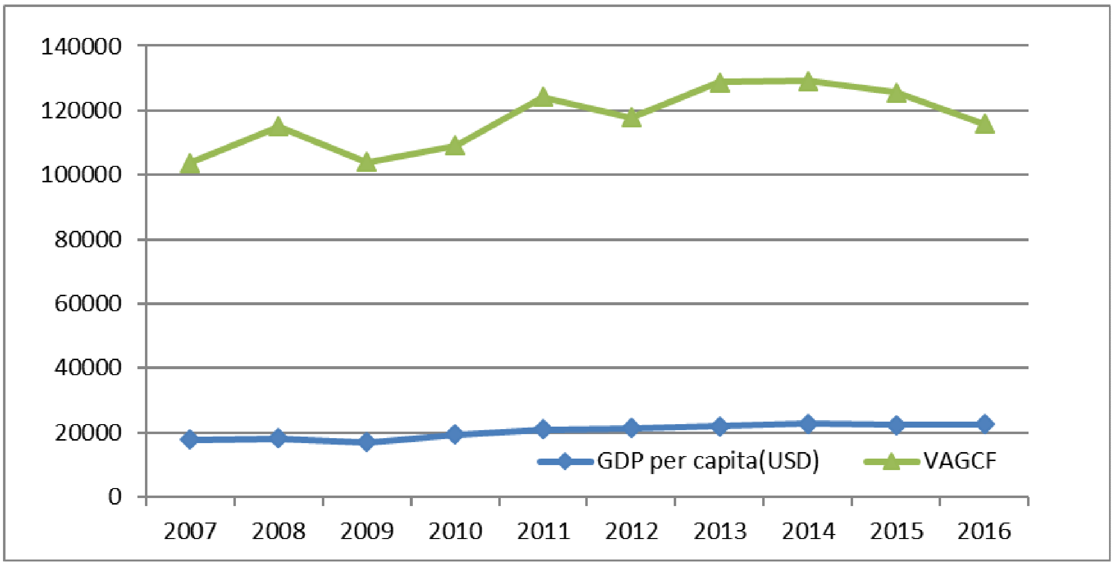

Figure 1. Trend of the value of the agricultural grain consumption footprint in Taiwan (2007–2016)

Note: compiled and drawn by this study

Efficiency Analysis Of Agricultural Grain Consumption Footprint In Taiwan

Agricultural grain consumption footprint intensity (AGCFI) refers to the area of the EF of agricultural grain consumption required for one additional unit GDP, defined as the ratio of agricultural grain consumption footprint to Taiwan's GDP. When the AGCFI value is higher, energy consumption is larger, and the EF efficiency of agricultural grain consumption is lower.

In Figure 2, the trend of AGCFI from 2007 to 2013 is satisfactory: the highest value was in 2007 (9.6*10-6 hm2/US$), which then declined until 2013 (7.7*10-6 hm2/US$), which is the lowest. Next, a continuous increase occurred until 2016 (8.6*10-6 hm2/US$). This finding indicates that the efficiency of agricultural grain consumption in Taiwan decreased gradually after 2013, and the economic value per unit area decreased continuously.

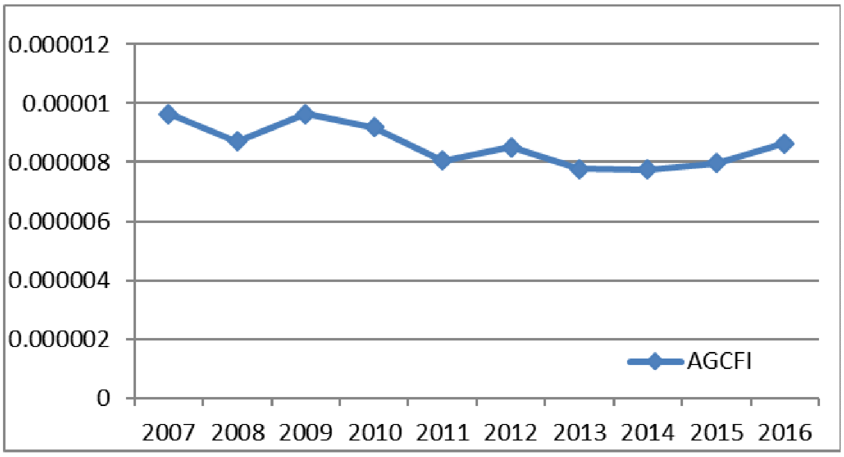

Figure 2. Trend of AGCFI in Taiwan

Note: compiled and drawn by this study

Analysis Of Stress Of Agricultural Grain Consumption EF

In Figure 3, the average arable area of Taiwan is approximately 807,813 ha, accounting for 22.43% of the total area. In terms of Taiwan's agricultural grain consumption, the average total EF was 1.12-fold in Taiwan. Regarding the arable area, the average total EF was 5.01-fold of Taiwan’s arable area, especially in 2016, when it was as high as 5.77-fold. This result indicates that the status of overutilization is serious in Taiwan.

In 2016, for example, the EF of agricultural grain consumption was 0.1946 ha/person, the population was 23,539,816, and the total EF was 4,580,848 ha. Calculated by referring to Taiwan's total area, it required 1.2 Taiwan to bear the agricultural grain consumption of the Taiwanese, and the consumption of agricultural grain only accounted for a few proportions of land use in Taiwan. Therefore, the status of environment overload is serious in Taiwan.

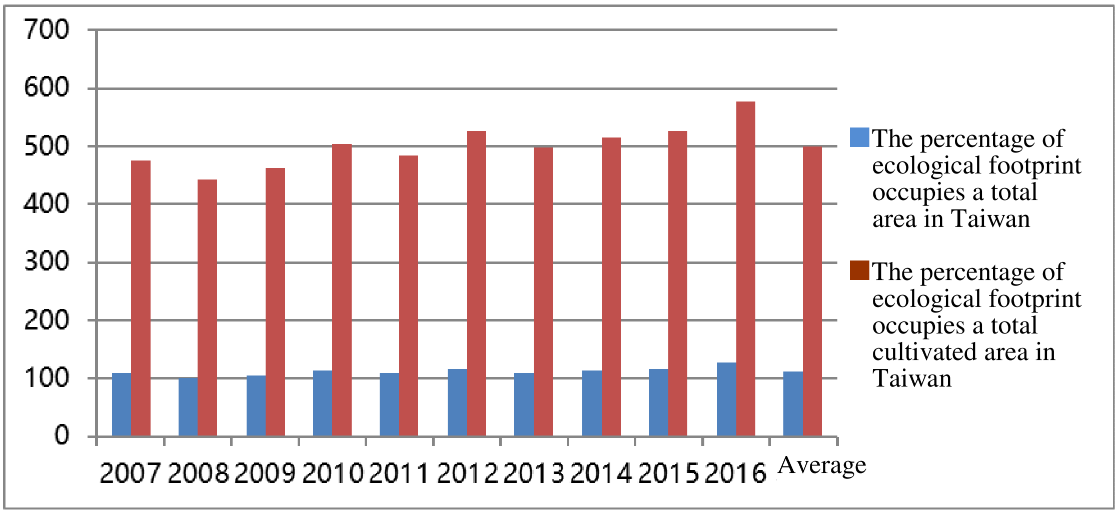

Figure 3. Percentage of the total EF of agricultural grain consumption occupying the total area of Taiwan over the years

Note: compiled and drawn by this study

Conclusion and Suggestions

From 2007 to 2016, the EF of agricultural grain consumption increased 1.2-fold in Taiwan, the arable land area that each individual could use decreased 1.1-fold, and the ratio of agricultural grain EF to occupied arable area increased 1.3-fold. However, the result of both stress and efficiency of ecological factors indicated that, starting in 2013, the efficiency of agricultural grain consumption decreased gradually, and the economic value per unit area reduced continuously.

In Taiwan, the land area is small and the arable land is limited. In the future, regarding the situation of the population continuing to increase naturally, industry and commerce will develop, agriculture will not be regarded, and the demand for other land uses will increase substantially; thus, the arable land will be manipulated constantly.

In this study, the trend of Taiwanese diet habits was that the EF of agricultural grain consumption would increase with the increase in miscellaneous grains consumption. In the future, the Taiwanese must change their dietary habits by eating more agricultural grain that has a higher unit yield and lower EF, such as sweet potatoes, fruits, and vegetables. The Taiwanese people must also treasure grains, cherish lands, reduce their personal EF to slow down the increase in the total EF.

The diversity of EF encourages many levels of action, but the energy of these actions is not enough to address the pressures facing agriculture. In addition, the diversity of EF is not yet integrated into broader policies, strategies, programs and actions. As a result, the underlying causes of loss of EF diversity have not been significantly reduced. Although this study has some understanding of the relationship between biodiversity, ecosystem services, and human well-being, the value of EF remains unrecognized in a broader policy and incentive structure.

The various contextual analyses of this study provide a wide range of alternatives to crisis resolution. Humankind's determination, cherish and protect the EF will benefit people in many ways. This study suggests that governments and practitioners can do the following to achieve sustainable development of the environment, including through better health conditions, greater food security and less poverty. It will also help mitigate climate change by strengthening ecosystem storage and the ability to absorb more carbon, as well as helping people adapt to climate change by increasing the resilience of ecosystems and reducing their vulnerability. Therefore, the opinions of this study will help to reduce prudent and cost-effective investments in international social risks.

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