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Assessment of Changes in Environmental Factors Affecting Aquaculture Production and Fisherfolk Incomes in China between 2010 and 2020

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Abstract: The vast expanse of China's land surface results in the country's environment varying from region to region. Environmental changes impact on China's industries, markets, and trade, indirectly affecting not only the country's economy but also the people who depend on aquaculture resources. Regional differentiation leads to an imbalance that severely affects social fairness and equity, which becomes a key factor limiting the sustainable development of the economy and society. Analysis and assessment of the changes in environmental factors affecting aquaculture production and fisherfolk's income in 31 regions of China between 2010 and 2020 aim to provide a reference for regional differentiation in the economic development of aquaculture in the different regions in China, representing an essential step towards achieving the coordinated development of rural regional areas. This study's assessment and analysis procedures adopted the principal component analysis method. The findings suggest that regional differences in Chinese fisherfolk's income and the environmental factors affecting China's aquaculture production are veritable. There have been subtle changes in regional differentiation over a decade. It is necessary to implement contextualized environmental management measures, concessionary taxation, and additional subsidies to address the different characteristics of China's different regions for the future development of environmental management and narrowing the income gap, to address both the income disparities in Chinese fisherfolk's income and environmental factors affecting Chinese aquaculture production, to achieve the harmonious development of rural regional areas.

Keywords: aquaculture economy; regional differentiation; principal component analysis

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1. Introduction

Agriculture makes a crucial contribution to the socio-economic growth and development of every country and region [1]. Fisheries and the aquaculture economy provide an integral part of China's agricultural economy [2]. Furthermore, in China, this represents a strategic facet to construct a harmonious society and promoting rural revitalization [3]. Fisheries and aquaculture have played an essential role in ensuring national food security and increasing the income of fisherfolk [4]. As the standard of living of the Chinese people improves, the levels of per capita disposable income, population, and urbanization are also rising [5]; this also drives additional demand for the production and consumption of aquaculture products in China [6].

Consequently, fisheries and aquaculture have become an important industrial pillar in China's national economic development. According to FAO research [7], China's fishing and aquaculture sector generated only 0.2 per cent of the overall agricultural production in 1949, while it contributed 12 per cent in 2014—a 60-fold increase. The export trade started out at USD 260 million in 1978 before climbing to a record of USD 30.8 billion in 2014—a gain greater than 110-fold. The economic benefits of fisheries and aquaculture are thus critical to China's agriculture economy's development. This is because exporting fisheries and aquaculture goods boosts China's financial earnings while increasing its foreign exchange reserves. In addition, China is rapidly expanding its foreign trade. Through the Belt and Road Initiative, it will continue to expand its national fisheries and aquaculture sector while enhancing international cooperation to expand the trade in fisheries and aquaculture while boosting the visibility of Chinese fisheries and aquaculture around the world. Asia will account for 89 per cent of the total world aquaculture production in 2030, according to FAO predictions [7]. China will, in the meantime, remain an essential worldwide producer, even while its share of overall output is forecast to fall from 58 per cent in 2018 to 56 per cent in 2030, owing to the continuance of the 13th Five-Year Plan's fishing and aquaculture reduction initiatives. Although the policy is expected to hinder the output of China's fisheries and aquaculture industry, it has no bearing on the vital role fisheries and aquaculture play in its national economy. It is furthermore foreseeable that China's fisheries and aquaculture industry are still poised to play an essential role in its future development. Because the fisheries and aquaculture value chains cover multiple sectors, from catch to processing and marketing, this generates different employment opportunities in the fisheries and aquaculture sector, with aquaculture-related employment having increased. According to the China Fisheries Statistical Yearbook 2019 [8], China's fishery and aquaculture population accounted for 37.6% of Asia's total fishery and aquaculture population in 2018 and about 1.35% of China's total population in 2018. Therefore, this large group of people working in the fisheries and aquaculture sector constitutes an essential concern for developing Chinese agriculture.

The income structure of Chinese fisherfolk is relatively complex. Household operating income generates the primary source of earnings for the total income of Chinese fisherfolk households. According to the China Fisheries Statistical Yearbook 2021 [9], in 2020, the operating income of Chinese fisherfolk accounted for 88.92%; salary income was 6.92%; transfer income was 3.57%; and property income generated the lowest proportion, which was only 0.6%. Historically, fisherfolk incomes were more dependent upon the performance of the primary sector [10], thus resulting from factors such as fishery and aquaculture resources, breeding diseases, natural hazards, and market prices and the trading situation, which directly or indirectly affected fisherfolks' income status in the current year as well as in successive years [11]. Environmental changes can both reduce aquaculture production and cause abiotic and biotic changes [12]. In addition, environmental changes, such as the greater incidence of typhoons and floods, likewise impact on inland aquaculture [13]. Fish diseases also affect aquaculture production because of bacterial and parasitic infections as these may bring about high fish mortality rates, which are detrimental to fisheries and aquaculture production [14]. According to the China Fisheries Statistical Yearbook 2021 [9], in 2020, typhoons and floods, diseases, droughts, pollution, and other factors, afflicted 70.92%, 15.38%, 7.15%, 1.04%, and 5.51% of the total aquaculture product farming area, respectively. These environmental changes carry implications for industry, markets, and trade, indirectly affecting both fisherfolk incomes and the Chinese economy.

Despite the sheer importance of China's fisheries and aquaculture to the world aquaculture economy, unfortunately, only a few studies have focused on China's aquaculture production environment and the incomes of Chinese fisherfolk. Most academic studies examining the impact of environmental factors on income have focused on other countries, such as Sri Lanka [15], the USA [16,17], Malaysia [18], or Indonesia [19]. Although some researchers have studied the impact of environmental changes on income in China [20–22], most scholars place more emphasis on farmers than fisherfolk. Some scholars have also studied the impact of environmental change on fisherfolk's income, such as the poverty trap proposed by Gao et al. [23]. However, because China is vast and the ecology of aquaculture varies from region to region, fisherfolk incomes may also vary by region, with regions in coastal areas more severely affected by typhoons and flooding than regions distant from the sea and major rivers. Furthermore, regions with developed industries are more severely affected by pollution than industrially backward areas. During this decade of development, China's economic development and rural areas have undergone dramatic alterations. The development of agriculture and aquaculture in China has also undergone significant changes with the intervention of government fisheries and aquaculture policies, environmental policies, and investments in fisheries and aquaculture technologies [24]. Therefore, there is a clear need to study and analyse the incomes of Chinese fisherfolk based on regional studies and the Chinese fisheries and aquaculture environment. Therefore, the questions here under study are as follows: Are regional differences in the incomes of Chinese fisherfolk and environmental factors affecting aquaculture in China? Are there regions in China where the environment for aquaculture production is unfavourable, and fisherfolk's incomes are not only low but have not improved over a decade and thus fall into the poverty trap? Based on these premises, we are at the following research hypothesis:

Hypothesis (H1). There are regional differences in the incomes of Chinese fisherfolk and in the environmental factors affecting aquaculture production.

Hypothesis (H2). There are regions in China where the aquaculture environment is unfavourable and fisherfolk incomes are low and did not improve for ten years, thus falling into a poverty trap.

2. Materials and Methods

2.1. Principal Component Analysis (PCA)

Principal component analysis is a technique for reducing dimensionality, where multiple indicators in the data are represented by a limited number of composite indicators that return a good representation of the original data in this analytical approach [25–27]. This essentially strives to describe the original data with as few variables as feasible to ascertain whether the relationship between them is linear in nature [28]. This analytical approach also collects uncorrelated composite indicators that constitute a collection of correlated variables [29]. As a result, principal components analysis (PCA) serves as an objective method for selecting indices with more considerable variability within the analysed observations and determining their weightings as a function of explained variance [30]. On the other hand, PCA is limited to retrospective analysis and is not suitable for future research. Nevertheless, this approach does allow for internal assessments between countries and regions [31].

2.2. Data Set and Variables

This paper covers 31 regions in mainland China (Hong Kong SAR, Macau SAR and Taiwan Province are not included in this study). In order to subsequently discuss the results more directly, this study divides the 31 regions of mainland China into four sections, namely, the Eastern, Central, Western, and Northeastern regions (Figure 1). The Eastern region includes Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan. The Central region includes Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan. The Western region includes Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang. The Northeastern region includes Heilongjiang, Jilin, and Liaoning. These 31 regions were chosen to represent mainland China, which is essential for our analysis of regional differentiation in China. Appendix A shows the variation in seawater and freshwater aquaculture in different Chinese regions. The region with the highest aquaculture production in China is the Eastern region of China, which accounted for 78.83% of China's total Seawater Aquaculture production in 2020, an increase of 0.46% compared to 2010. Fujian is the region with the highest production of Seawater Aquaculture in the Eastern region, with production rising by 40.5% between 2020 and 2010; Freshwater Aquaculture production in the Eastern region of China accounts for 37.18% of China's total Freshwater Aquaculture production in 2020, a decrease of 14.92% compared to 2010. Guangdong is the largest producer of Freshwater Aquaculture in the Eastern region, with a 21.34% increase in Freshwater Aquaculture in 2020 compared to 2010. There is no major production of Seawater Aquaculture in the Central, Western, and Northeastern regions of China, and most regions do not have Seawater Aquaculture. However, Freshwater Aquaculture production in Central China surpassed that in Eastern China in 2020, accounting for 41.31% of the total Freshwater Aquaculture production in China, an increase of 5.03% compared to 2010.

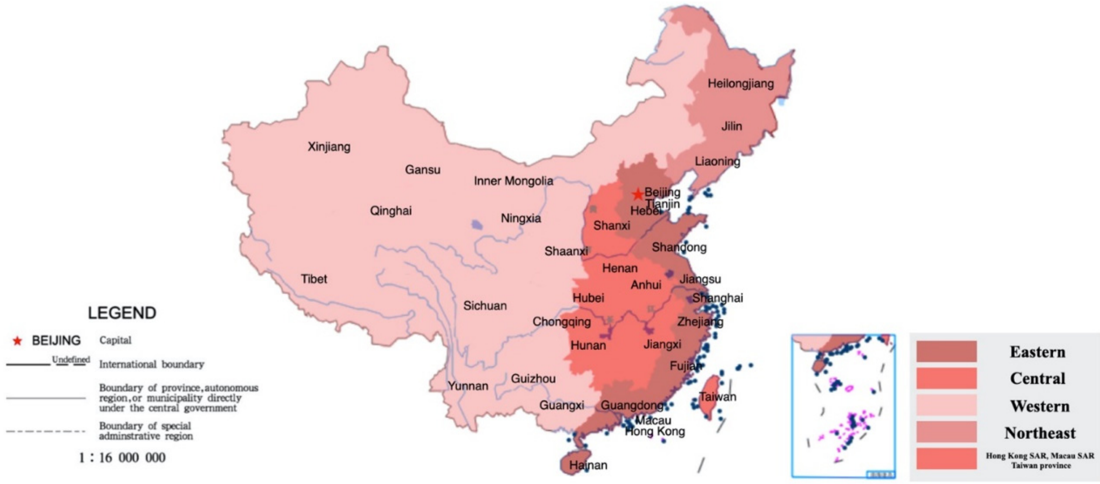

Figure 1. Regional divisions of Eastern, Central, Western, and Northeastern China (The map of China was generated by the standard map online service; URL link: http://bzdt.ch.mnr.gov.cn (accessed on 7 May 2022)).

The data for this study—the environmental and income indicators—were obtained and referenced from the China Fisheries Statistical Yearbook 2011 and the China Fisheries Statistical Yearbook 2021 [9,32]. Based on the above research hypotheses and the data available, the variables in this study were organized into two different types, specifically, environmental variables and income variables (Table 1). In particular, the environmental variables for the affected farming areas were those farming areas that lost at least 10% of their aquaculture production due to disaster. In aquaculture, there are areas that are not stocked with fry or stocked with only a small amount of fry for general management and that do not fall into the aquaculture category. Freshwater aquaculture consists of surface areas of freshwater waters where aquaculture products are farmed, including ponds, lakes, reservoirs, rivers, ditches, and others. Due to limitations in data acquisition, the study only covers aquaculture and fisherfolk engaged in aquaculture production in China. The statistical software deployed for this study was SAS JMP Pro16.

2.3. Analysis of Data

The first step in principal component analysis is to observe the scree plot that the procedure generates, to analyse the income of Chinese fisherfolk in 2010 and 2020. The importance of the principal components can be seen (Figure 2), whereby the eigenvalues of the first three principal components in 2010 and 2020 are relatively elevated and steep, implying greater variability in the first three components. Hence, this may reflect how the first three principal components chosen for this study represent the original variables for the income of Chinese fisherfolk. When more principal components are included in the study, which explains most of the variance in the original data, then the PCA model performs more effectively. However, only the principal components that explain most variance (70–95%) should be retained [33]. Therefore, it is crucial to examine the variations in the eigenvalues of Chinese fisherfolk incomes in 2010 and 2020 (Table S1). Regarding the eigenvalues of Chinese fisherfolk incomes in 2010 and 2020, the cumulative percentage of the first three principal components, Prin1, Prin2, and Prin3, reached 97.647% (2010) and 90.74% (2020). Therefore, Prin4 is not included in the study of Chinese fisherfolk incomes in 2010 and 2020. The principal component analysis of the environment resembled the principal component analysis of income. The first step involved analysing the scree plot generated for the environmental factors in China (Figure 3). This demonstrated the relatively higher and steeper eigenvalues for the first four principal components in 2010 and the first three principal components in 2020, which implies greater variation in the first four principal components in 2010 and the first three principal components in 2020. Hence, this may be understood as meaning that the first four principal components in 2010 and the first three principal components in 2020 represent the original variables for this study on the environmental factors affecting Chinese aquaculture production. The eigenvalues of the environmental factors affecting aquaculture production in China in 2010 and 2020 (Table S1) had a cumulative percentage for the first four principal components, Prin1, Prin2, Prin3, and Prin4, of 97.283% (2020). Therefore, Prin5 was not included in the 2020 study. The cumulative proportion of the first three principal components, Prin1, Prin2, and Prin3, reached 86.585% (2010), which already clearly exceeds 70%. Therefore, the study does not consider Prin4 and Prin5 for analysis in the 2010 study.

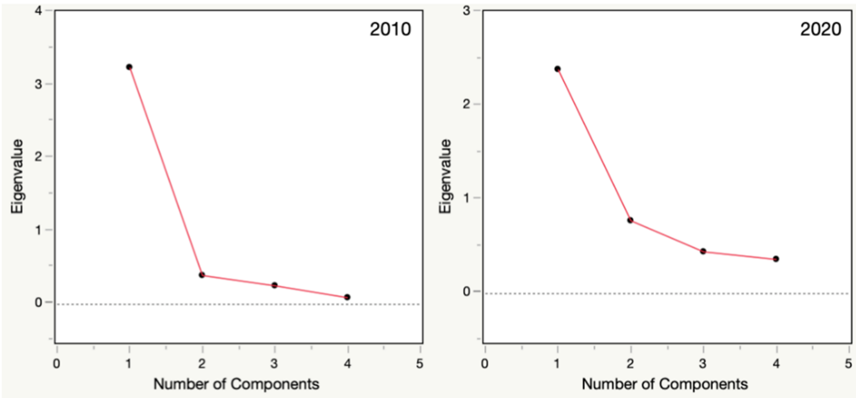

Figure 2. Scree plot of Chinese fisherfolk incomes in 2010 and 2020. Source: Authors' own calculations based on data from China Fisheries Statistical Yearbook 2011 and China Fisheries Statistical Yearbook 2021.

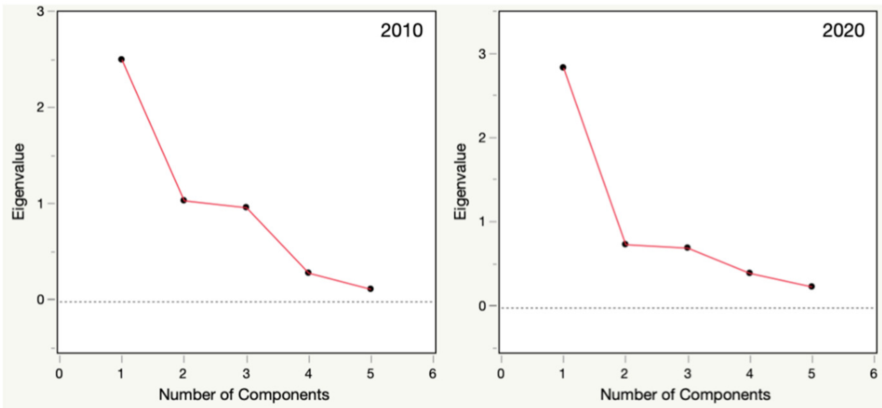

Figure 3. Scree plot of environmental conditions in different Chinese regions in 2010 and 2020. Source: Authors' own calculations based on data from China Fisheries Statistical Yearbook 2011 and China Fisheries Statistical Yearbook 2021.

The models $F1_{2010}$, $F1_{2020}$ and $F2_{2010}$, $F2_{2020}$ were obtained from the analysis of principal components (see Supplementary Material for details of the analysis process), and the meaning of the variables in the model is given in the Supplementary Material (Equations (S1)–(S13)). Hence, we applied the model $F1_{2010}$ Equation (1) and $F1_{2020}$ Equation (2) to assess Chinese fisherfolk incomes in 2010 and 2020.

Table 1. Environmental variables affecting aquaculture production in China and the income variables of Chinese fisherfolk.

Environmental Variables (Unit: Hectares)		
TFA	Aquaculture farming areas affected by typhoons and flooding	Economic losses due to damage to aquaculture facilities and loss of aquaculture products caused by meteorological disasters such as typhoons and floods. Farming areas affected by typhoons and flooding include aquaculture and freshwater farming areas (Unit: hectares)
DA	Aquaculture farming areas affected by diseases	Bacterial and parasite illnesses can cause major economic losses deriving from high fish mortality rates. Farming areas affected by diseases include aquaculture and freshwater farming areas (Unit: hectares)
DRA	Aquaculture farming areas affected by droughts	Drought causes a decrease in the volume of farming water, making water quality control more difficult and causing a serious lack of oxygen in the water, resulting in the death of a large number of farming species; during the hot season, water quality drops, making it easier for epidemics to occur and spread.
PA	Aquaculture farming areas affected by pollution	Eutrophication of the aquaculture environment is mostly caused by aquaculture pollution, which can result in red tides and fish illnesses.
OA	Aquaculture farming areas affected by environmental factors other than typhoons, floods, disease, drought, and pollution	Environmental factors other than typhoons, floods, disease, drought, and pollution.
Income Variables (Unit: CNY)		
HOI	Household operating income	Household operating income is derived through the production and administration of goods and services in the family.
SI	Salary income	Salary income refers to the total remuneration for work and benefits received by fisherfolk in their household through various means, including wages earned from productive work in the aquaculture industry and wages earned from work in other industries.
PI	Property net income	Property net income is the net income received by fisherfolk households or their member in return for placing financial assets and natural resources at the disposal of other institutions, households or individuals, and after deduction of relevant fees and charges. (Examples: net interest income, dividend income, net income from savings insurance, net rental income from the transfer of contracted land or water rights, etc.).
TI	Transfer income	Transfer income refers to various recurrent transfers from the government, institutions, and social teams to fisherfolk. (Examples: pensions or retirement benefits, social assistance and subsidies, agricultural subsidies, policy subsistence subsidies, etc.) transferred to fisherfolk by the government, non-administrative units, and social teams.

Note: Factory farming and deep-water netting are not included in the aquaculture sector; factory farming and paddy farming are not included in the total freshwater aquaculture area.

$$F1_{2010} = 3.2496V1_{2010} + 0.3988V2_{2010} + 0.2574V3_{2010} \quad (1)$$

$$F1_{2020} = 3.985V1_{2020} + 0.7937V2_{2020} + 0.5095V3_{2020} \quad (2)$$

Similarly, the model $F2_{2010}$ Equation (3) and $F2_{2020}$ Equation (4) served to assess the environmental factors affecting Chinese aquaculture production in 2010 and 2020:

$$F2_{2010} = 2.5202U1_{2010} + 1.0559U2_{2010} + 0.98425U3_{2010} + 0.3039U4_{2010} \quad (3)$$

$$F2_{2020} = 2.8559U1_{2020} + 0.7572U2_{2020} + 0.7161U3_{2020} \quad (4)$$

3. Results

As set out in the previous section, this study derives its models from assessing the principal components of Chinese fisherfolk incomes and the environmental factors affecting

Chinese aquaculture production in 2010 and 2020 (Equations (1)–(4)) by incorporating the principal component variables for the 31 regions and the Chinese fisherfolk incomes and environmental factors affecting Chinese aquaculture production in 2010 and 2020, allowing us to obtain a comprehensive score for, and thus ranking of, these 31 regions in 2010 and 2020, as well as observing the changes in ranking over the decade studied (Table 2). The study concludes by classifying Chinese fisherfolk incomes and the aquaculture production environment into four categories based on previous ratings of fisherfolk incomes and the environment.

Table 2. Changes in the comprehensive environmental and income evaluations of China's regions. Source: Authors' own calculations based on data from the China Fisheries Statistical Yearbook 2011 and China Fisheries Statistical Yearbook 2021.

	Region	$F1_{2010}$	Ranking	$F1_{2020}$	Ranking	Ranking Changes	$F2_{2010}$	Ranking	$F2_{2020}$	Ranking	Ranking Changes
Eastern	Beijing	−4.21	25	−3.01	21	4	−3.18	26	−2.97	26	0
	Fujian	8.5	4	4.03	9	−5	−1.94	15	−2.77	19	−4
	Guangdong	17.45	1	2.83	10	−9	1.32	10	4.73	6	4
	Hainan	4.09	8	−3.77	24	−16	−2.52	18	−2.88	22	−4
	Hebei	−3.02	16	4.17	8	8	−2.59	20	−2.26	11	9
	Jiangsu	8.01	5	14.54	2	3	4.65	6	15.99	1	5
	Shandong	9.94	2	6.33	6	−4	3.58	7	2.64	8	−1
	Shanghai	6.68	6	11.97	4	2	−2.91	23	−2.85	20	3
	Tianjin	−2.46	14	14.11	3	11	−2.92	24	−2.33	14	10
	Zhejiang	9.87	3	17.52	1	2	−1.65	14	−0.36	10	4
Central	Anhui	−1.27	12	−0.6	16	−4	8.27	2	9.95	2	0
	Henan	−3.96	19	−1.96	19	0	−2.71	21	−0.26	9	12
	Hubei	−0.37	11	1.99	11	0	14.48	1	8.72	3	−2
	Hunan	−1.95	13	−1.26	18	−5	5.92	3	6.12	5	−2
	Jiangxi	−2.73	15	−0.42	15	0	4.94	4	7.54	4	0
	Shanxi	−4.3	26	−9.46	28	−2	−3.22	28	−2.99	28	0
Western	Chongqing	−4.08	22	1.49	12	10	−2.56	19	−2.85	21	−2
	Gansu	−3.85	18	−11.71	30	−12	−3.23	29	−2.99	29	0
	Guangxi	0.21	10	4.2	7	3	0.35	11	−2.33	13	−2
	Guizhou	−4.38	29	−9.51	29	0	−1.29	12	−2.7	16	−4
	Inner Mongolia	−4.32	27	−7.17	26	1	−1.95	16	−2.28	12	4
	Ningxia	−4.32	28	−2.81	20	8	−3.16	25	−2.98	27	−2
	Qinghai	−4.42	30	−8.49	27	3	−3.23	30	−2.99	30	0
	Shaanxi	2.59	9	1.36	13	−4	−2.81	22	−2.93	24	−2
	Sichuan	−3.36	17	0.02	14	3	−1.3	13	−2.75	18	−5
	Tibet	−4.42	30	−18.05	31	−1	−3.23	31	−2.99	30	1
	Xinjiang	−4.1	23	−3.18	22	1	−2.15	17	−2.74	17	0
	Yunan	−4.03	20	−3.51	23	−3	4.79	5	−2.38	15	−10
Northeast	Heilongjiang	−4.07	21	−1.02	17	4	−3.21	27	−2.95	25	2
	Jilin	−4.12	24	−7.1	25	−1	1.87	8	−2.93	23	−15
	Liaoning	6.43	7	8.48	5	2	1.58	9	2.76	7	2

The results in Table 2 clearly depict the regional variations in Chinese fisherfolk incomes and the environmental factors affecting aquaculture production. Most Chinese regions exhibited modest changes in their aquaculture production environment and fisherfolk incomes over the decade, with a few regions registering significant changes in their rankings.

Taken collectively, the Eastern and Central regions were ranked higher than the Western and Northeastern regions of China in terms of environmental considerations, implying relatively unfavourable environmental conditions. The three regions in the country facing the most severe environmental conditions are Jiangsu (Eastern Region), which ranked first in 2020 and increased by five places in 2010; Anhui (Central Region), which ranked second and remained in the same place in 2020 as in 2010; and Hubei (Central Region), which ranked third in 2020, two places worse than in 2010. Although the aquaculture production environment in the Eastern and Central regions is relatively challenging, the environmental factors for aquaculture production in the Eastern and Central regions have improved markedly, mainly benefiting from the Ministry of Agriculture's release of the *Demonstration Project Construction Plan for the Comprehensive Management of Agricultural Surface Source Pollution in Key Watersheds (2016–2020)*; this plan proposes strengthening the governance of the hydro-environment in the Dongting Lake (Hunan region), Poyang Lake (Jiangxi region), Taihu Lake (Jiangsu region), and other essential basins, demanding a built-up urban region without large-scale floating black and smelly water bodies, riverbanks, and illegal outfalls, as well as a continuous reduction in the city's total discharge of major water pollutants. Local governments have correspondingly introduced personalized implementation plans for the local environment, such as the Hanchuan City region in Hubei, which introduced the *Hanchuan City Water Pollution Prevention and Control Action Scheme Implementation Plan* in June 2017. Nevertheless, the Eastern and Central regions still rank high when compared to the Western and Northeastern regions, implying the need to improve the aquaculture production environment in the Eastern and Central regions, which constitute China's most productive aquaculture regions.

The main problems in Western and Northeastern China relate to the low income of fisherfolk. However, some regions, such as Guangxi (ranked 7th in 2020) and Liaoning (ranked 5th in 2020), have relatively high-income rankings at the national level. However, most regions report low rankings, such as Tibet (Western Region), which ranks in 31st place, a decrease of 1 place in 2020 compared to 2010; Gansu (Western Region), which is ranked in 30th place, decreasing 12 places between 2020 and 2010; and Guizhou (Western Region), which ranks in the 29th place, unchanged in the decade through to 2020. This mainly stems from the Western and Northeastern regions of China lacking the aquatic resources of the Eastern and Central regions due to their geographical location.

Below, there is a comprehensive assessment of the aquaculture environment and levels of fisherfolk income. Chinese fisherfolk incomes and aquaculture production environment fall into four categories based on previous ratings of fisherfolk incomes and the environment (Table 2), which are as follows: the F1+ F2+ group represents the region where fisherfolk register high incomes while also being heavily impacted by the environment; the F1+ F2− group represents regions with high fisherfolk incomes but which are not severely affected by the environment; the F1− F2+ group represents regions where fisherfolk report low incomes while also being severely affected by the environment; and the F1− F2− group represents regions where fisherfolk earn only low incomes but are not severely affected by the environment. To visualize the changes over this decade, this study includes a map displaying the different regional groups and changes between 2010 and 2020 according to the classification described above (Figure 4).

For 2010, F1+ F2+ includes Jiangsu and Shandong; F1+ F2− includes Guangdong, Liaoning, Shanghai, Fujian and Zhejiang; F1− F2+ includes Yunnan, Jiangxi, Hunan, and Anhui; and the F1− F2− group spans Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Jilin, Heilongjiang, Henan, Hubei, Guangxi, Hainan, Sichuan, Chongqing, Guizhou, Tibet, and Shaanxi. For 2020, F1+ F2+ includes Jiangsu and Hubei; F1+ F2− includes Tianjin, Hebei, Liaoning, Shanghai, Zhejiang, Fujian, Shandong, Guangdong, Guangxi, Chongqing, Sichuan, and Shaanxi; F1− F2+ includes Anhui and Jiangxi; and F1− F2− consists of Beijing, Shanxi, Inner Mongolia, Jilin, Heilongjiang, Henan, Hunan, Hainan, Guizhou, Yunnan, Tibet, Gansu, Qinghai, Ningxia, and Xinjiang.

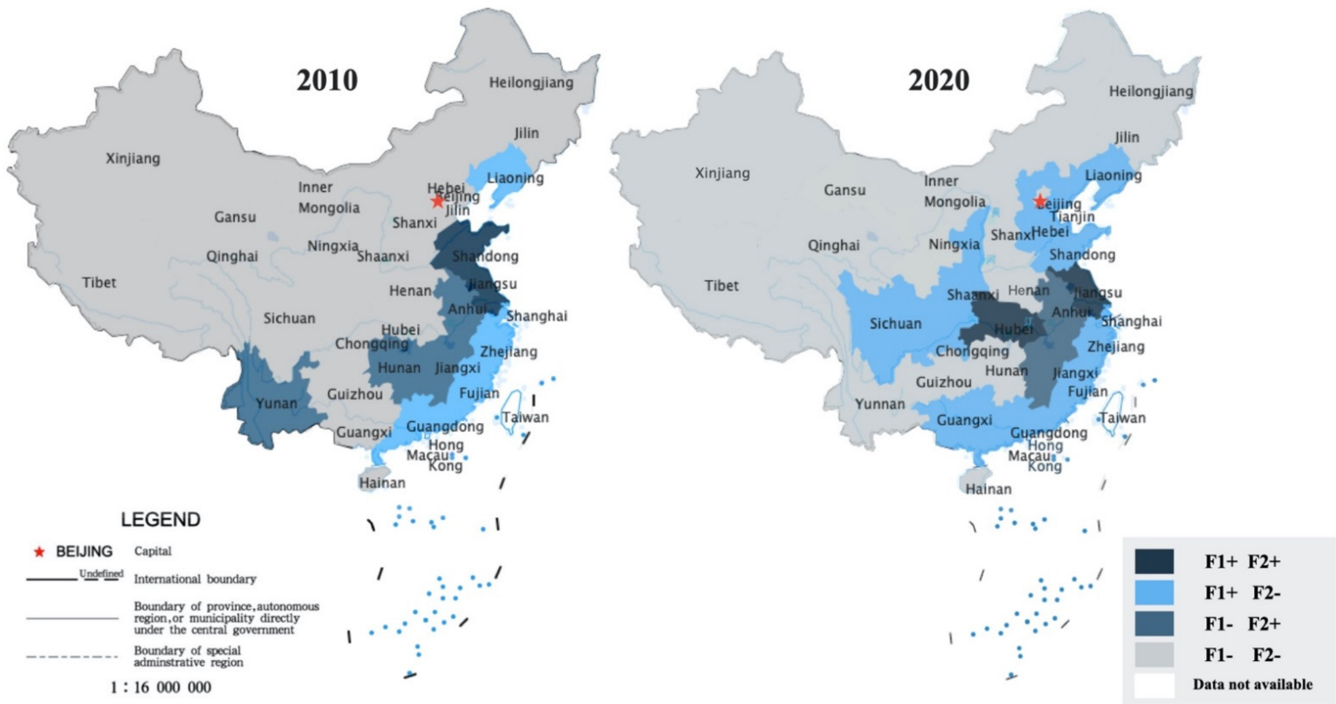

Figure 4. Changes in the evaluation of the comprehensive environmental and income of China's regions. The Chinese map was generated by the standard map online service, URL link: http://bzdt.ch.mnr.gov.cn (accessed on 9 May 2022).

4. Discussion

Environmental factors are inextricably linked to the incomes of farmers [34]. Environmental factors can drag down incomes while the differences in environmental factors prevailing in different regions can drive regional income inequalities. The excessive wealth gap in China is not conducive to social harmony and development and may lead to social conflicts and instability. In the long run, an excessive gap between the rich and the poor is inconsistent with the principles of socialism, the essence of which is "to liberate the productive forces, develop them, eradicate exploitation, eliminate polarization and ultimately achieve common prosperity" [35]. Market competition will spontaneously and continuously widen this wealth gap, and if not appropriately regulated, this will drive polarization. Therefore, when the gap between the rich and the poor reaches a certain level, the state and the government should intervene and regulate to reduce this excessive gap. Otherwise, social conflicts will emerge if this is left to widen. Only by taking appropriate measures to narrow the gap between the rich and the poor and raise the income levels of the majority of the population will it be possible to foster coordination and healthy interactions between different social classes and interest groups, forming equal, friendly, and harmonious interpersonal relationships and maintaining a stable and orderly social environment that thereby ensures the achievement of the ambitious goal of building a moderately prosperous society in all aspects [36].

This study assessed the changes in the income of fisherfolk and the environmental factors affecting aquaculture production in the 31 regions of China in 2010 and 2020 by applying principal component analysis. The findings unveiled regional differences in the comprehensive incomes of Chinese fisherfolk and changes in the environmental factors affecting aquaculture production in China over the last decade.

This study may thus report that the Shandong region was F1+ F2+ in 2010 and F1+ F2− in 2020. This represents a significant improvement in the environmental factors affecting aquaculture production in Shandong over this decade. The most significant environmental factors affecting aquaculture production in Shandong are DA (diseases) and PA (pollution), with DA decreasing by 58.12% in 2020 compared to 2010 and PA down by 88.32% in 2020 in comparison with 2010.

Hubei region fell into the F1− F2− group in 2010 but was F1+ F2+ in 2020. This conveys how the comprehensive income of fisherfolk in the Hubei region changed relatively significantly over the decade, with the most significant increases being in SI (salary income) and TI (transfer income), with SI soaring by 2577.01% in the decade to 2020 and TI advancing by 1465.28% over the same period. The environmental factors affecting aquaculture production in Hubei also improved significantly, with the most extensive changes affecting aquaculture production in Hubei being DA, down by 84.15% in the decade between 2010 and 2020, while PA plummeted by 99.09% over the same period.

Hunan and Yunnan are F1− F2+ in 2010 and F1− F2− in 2020, thus indicating a significant improvement in the environmental factors affecting aquaculture production in Hunan and Yunnan over the decade. In Hunan, DA dropped by 42.72% and PA decreased by 81.91%. The most significant environmental factors affecting aquaculture production in the Yunnan region were PA, which was down by 98.77%, and DRA (droughts), which decreased by 96.45% over this period.

Tianjin, Hebei, Guangxi, Chongqing, Sichuan, and Shaanxi regions moved from F1− F2− in 2010 to F1+ F2− in 2020. This conveys how fisherfolk incomes in these regions have increased relatively noticeably over the decade.

In turn, the following regions remained broadly the same over the decade, with the Jiangsu region remaining F1+ F2+ in 2010 and 2020. Liaoning, Shanghai, Zhejiang, Fujian, and Guangdong were F1+ F2− in both 2010 and 2020 while Anhui and Guangxi retained their F1− F2+ classification in both 2010 and 2020. Meanwhile, Beijing, Shanxi, Inner Mongolia, Jilin, Heilongjiang, Henan, Hainan, Guizhou, Tibet, Gansu, Qinghai, Ningxia, and Xinjiang registered as F1− F2− in both 2010 and 2020.

Therefore, the findings of this study support Hypothesis 1, as there are clearly regional differences in environmental factors affecting aquaculture production and fisherfolk incomes in China.

The F1− F2+ regions in 2010 were Yunnan, Jiangxi, Hunan, and Anhui; in 2020, these regions consisted of Yunnan (F1− F2 −), Jiangxi (F1− F2+), Hunan (F1− F2), and Anhui (F1− F2+). The study found that the comprehensive income of fisherfolk in these areas remained in the low comprehensive income category. Consequently, this study also underpins Hypothesis 2, as Anhui and Jiangxi did not improve significantly. Regions like these exist in China.

This study is in line with the findings of Huibo's study [37]. Huibo assessed rural development in China by applying the TOPSIS method to demonstrate that the differentiation of rural areas in China is authentic, thus corroborating Hypothesis 1. The same study of environmental change and income inequality is evident in China's aquaculture industry and in the agriculture of other countries, such as Bangladesh [38].

This study also supports the study of Angelsen et al. [39], who reported how regions with low comprehensive fisherfolk incomes will exacerbate the degradation of their resource and ecological environments. In both 2010 and 2020, the regions facing low comprehensive assessments of fisherfolk incomes and severe environmental conditions were Anhui and Jiangxi, with this thereby supporting the poverty trap concept of Gao et al. [23]. In this decade, Anhui and Jiangxi fell into a vicious cycle of "environmental degradation–income reduction–environmental degradation"; this corroborates Hypothesis 2. To improve the current situation, this paper makes the following recommendations:

(1) Improving the aquaculture production environment in China should be approached from two directions. Firstly, the management systems for the aquaculture production environment in the Central region require strengthening to reduce the negative impacts of environmental pollution on aquaculture production. This involves reducing the pollution in the local environment caused by pesticides and fertilizers, controlling industrial sources of pollution, and adequately treating rural sewage. The objective involves striving to minimize the extent of the negative impacts of environmental

pollution on aquaculture production. The second facet is to strengthen the training of Chinese fisherfolk and deepen their knowledge of aquaculture and the environment, thus raising their awareness and understanding of the rational use of pesticides and fertilizers, to allow professionals to assess the intensity of pesticide and fertilizer run-off and the timing of application around rainfall as well as providing farmers and fisherfolk with advance warning. This seeks to avoid the application of pesticides and fertilizers before heavy rains to reduce the loss of pesticides and fertilizers, thus reducing the flows into rivers and other agricultural watercourses caused by rainwater carrying away pesticides and fertilizers. Simultaneously, it is essential to select the fertilizers and pesticides appropriate to the specific environment of the region, to thoroughly evaluate the impact on the regional ecosystem and to strive to selectively apply fertilizers and pesticides through both balanced and effective practices.

(2) An improvement in fisherfolk incomes should be supported by government subsidies (transfer income) in those regions (Northeastern and Western regions) severely affected by the natural environment and where fisherfolk incomes remain low. Additionally, developing green fisheries and aquaculture production should be supported to boost fisherfolk incomes through different channels. Furthermore, it is vital to encourage and provide fisherfolk with free training courses on aquaculture farming and environmental pollution, thereby increasing the awareness of the ecological protection of the aquaculture industry.

5. Conclusions

Results in the present work indicate regional differences in the incomes of Chinese fisherfolk and the environmental factors affecting aquaculture production. Meanwhile, in Anhui and Jiangxi, where the aquaculture environment is unfavourable, fisherfolk incomes are low and did not improve for ten years, thus falling into a poverty trap.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/fishes7040192/s1, Table S1: Eigenvalues and partial contribution of variables of Chinese fisherfolk's income in 2010 and 2020; Table S2: Eigenvalues and partial contribution of variables of aquaculture environmental conditions in different Chinese regions in 2010 and 2020.

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Appendix A

Table A1. Yield variation in Seawater Aquaculture and Freshwater Aquaculture in different Chinese regions. Source: Authors' own calculations based on data from the *China Fisheries Statistical Yearbook 2011* and *China Fisheries Statistical Yearbook 2021*.

	Units: Ton	Seawater Aquaculture			Freshwater Aquaculture		
		2010	2020	Changes (%)	2010	2020	Changes (%)
Eastern	Beijing	-	-	-	50,202	21,079	−138.16
	Tianjin	14,212	5155	−175.69	296,272	216,994	−36.53
	Hebei	329,308	448,802	26.63	388,453	258,953	−50.01
	Shanghai	-	-	-	162,479	83,555	−94.46

Table A1. *Cont.*

	Units: Ton	Seawater Aquaculture			Freshwater Aquaculture		
		2010	**2020**	**Changes (%)**	**2010**	**2020**	**Changes (%)**
Eastern	Jiangsu	785,173	915,258	14.21	2,907,598	3,178,892	8.53
	Zhejiang	825,730	1,270,357	35	875,020	1,171,254	25.29
	Fujian	3,038,990	5,107,162	40.5	659,668	839,379	21.41
	Shandong	3,962,643	4,970,985	20.28	1,244,018	1,081,348	−15.04
	Guangdong	2,490,688	3,291,325	24.33	3,146,669	4,000,107	21.34
	Hainan	184,162	270,955	32.03	296,413	354,387	16.36
	Total Aquaculture in the Eastern region	11,630,906	16,279,999	28.56	10,026,792	11,205,948	10.52
	Total aquaculture in the Eastern region as a percentage of national aquaculture (%)	78.47	78.83	0.46	42.73	37.18	−14.92
Central	Shanxi	-	-	-	30,869	44,040	29.91
	Anhui	-	-	-	1,617,241	2,109,524	23.34
	Jiangxi	-	-	-	1,860,892	2,420,568	23.12
	Henan	-	-	-	546,200	878,603	37.83
	Hubei	-	-	-	3,267,281	4,533,682	27.93
	Hunan	-	-	-	1,883,332	2,463,211	23.54
	Total Aquaculture in the Central region	-	-	-	9,205,815	12,449,628	26.06
	Total aquaculture in the Central region as a percentage of national aquaculture (%)	-	-	-	39.23	41.31	5.03
Western	Chongqing	-	-	-	213,345	524,116	59.29
	Gansu	-	-	-	12,300	14,353	14.3
	Guangxi	877,408	1,425,970	38.47	1,093,701	1,335,494	18.11
	Guizhou	-	-	-	75,838	233,024	67.45
	Inner Mongolia	-	-	-	83,133	111,904	25.71
	Ningxia	-	-	-	89,845	149,533	39.92
	Qinghai	-	-	-	1565	18,526	91.55
	Shaanxi	-	-	-	56,138	161,196	65.17
	Sichuan	-	-	-	992,605	1,538,002	35.46
	Tibet	-	-	-	72	96	25
	Xinjiang	-	-	-	90,913	152,032	40.2
	Yunnan	-	-	-	274,636	606,137	54.69
	Total Aquaculture in the Western region	877,408	1,425,970	38.47	2,984,091	4,844,317	38.4
	Total aquaculture in the Western region as a percentage of national aquaculture (%)	5.92	6.9	14.27	12.72	16.07	20.89
Northeast	Heilongjiang	-	-	-	352,815	608,300	42
	Jilin	-	-	-	146,202	217,501	32.78
	Liaoning	2,314,694	2,947,318	21.46	749,628	811,651	7.64
	Total Aquaculture in the Northeast region	2,314,694	2,947,318	21.46	1,248,645	1,637,452	23.74
	Total aquaculture in the Northeast region as a percentage of national aquaculture (%)	15.62	14.27	−9.43	5.32	5.43	2.06

References

1. Meijerink, G.; Roza, P. *The Role of Agriculture in Development*; Markets, Chains and Sustainable Development Strategy and Policy Paper; Wageningen University & Research, Stichting DLO: Wageningen, The Netherlands, 2007; p. 5.
2. FAO. Fishery and Aquaculture Country Profiles China. In *Country Profile Fact Sheets. Fisheries and Aquaculture Division [online]*; FAO: Rome, Italy, 2022.

3. Chen, X. Review of China's agricultural and rural development: Policy changes and current issues. *China Agric. Econ. Rev.* **2009**, *1*, 121–135. [CrossRef]
4. Finegold, C. *The Importance of Fisheries and Aquaculture to Development*; The Royal Swedish Academy of Agriculture and Forestry: Stockholm, Swedish, 2009.
5. Wang, Z.; Yang, L. Indirect Carbon Emissions in Household Consumption: Evidence from the Urban and Rural Area in China. *J. Clean. Prod.* **2014**, *78*, 94–103. [CrossRef]
6. Wijsman, J.W.M.; Troost, K.; Fang, J.; Roncarati, A. Global production of marine bivalves. Trends and challenges. In *Goods and Services of Marine Bivalves*; Smaal, A., Ferreira, J., Grant, J., Petersen, J., Strand, Ø., Eds.; Springer: Berlin/Heidelberg, Germany, 2019; pp. 7–26.
7. FAO. *The State of World Fisheries and Aquaculture 2020: Sustainable Development in Action*; Chinese article; FAO: Rome, Italy, 2020.
8. Ministry of Agriculture and Rural Affairs. *China Fisheries Statistical Yearbook*; Ministry of Agriculture and Rural Affairs: Beijing, China, 2019.
9. Ministry of Agriculture and Rural Affairs. *China Fisheries Statistical Yearbook*; Ministry of Agriculture and Rural Affairs: Beijing, China, 2021.
10. Amadu, I.; Armah, F.A.; Aheto, D.W. Assessing Livelihood Resilience of Artisanal Fisherfolk to the Decline in Small-Scale Fisheries in Ghana. *Sustainability* **2021**, *13*, 10404. [CrossRef]
11. Béné, C. Resilience of local food systems and links to food security—A review of some important concepts in the context of COVID-19 and other shocks. *Food Secur.* **2020**, *12*, 805–822. [CrossRef]
12. Barange, M.; Bahri, T.; Beveridge, M.C.M.; Cochrane, K.L.; Funge-Smith, S.; Poulain, F. *Impacts of Climate Change on Fisheries and Aquaculture: Synthesis of Current Knowledge, Adaptation and Mitigation Options*; FAO Fisheries and Aquaculture Technical Paper No. 627; FAO: Rome, Italy, 2018.
13. Harrod, C.; Ramírez, A.; Valbo-Jørgensen, J.; Funge-Smith, S. *How Climate Change Impacts Inland Fisheries*; Fisheries and Aquaculture Technical Paper No. 627; FAO: Rome, Italy, 2018.
14. Anjur, N.; Sabran, S.F.; Daud, H.M.; Othman, N.Z. An update on the ornamental fish industry in Malaysia: Aeromonas hydrophila-associated disease and its treatment control. *Vet. World* **2021**, *14*, 1143–1152. [CrossRef]
15. Keerthiratne, S.; Tol, R.S.J. Impact of natural disasters on income inequality in Sri Lanka. *World Dev.* **2018**, *105*, 217–230. [CrossRef]
16. Lynham, J.; Noy, I.; Page, J. The 1960 Tsunami in Hawaii: Long-Term Consequences of a Coastal Disaster. *World Dev.* **2017**, *94*, 106–118. [CrossRef]
17. Boustan, L.P.; Kahn, M.E.; Rhode, P.W.; Yanguas, M.L. The effect of natural disasters on economic activity in US counties: A century of data. *J. Urban Econ.* **2020**, *118*, 103257. [CrossRef]
18. Abu Samah, A.; Shaffril, H.A.M.; Hamzah, A.; Abu Samah, B. Factors Affecting Small-Scale Fishermen's Adaptation Toward the Impacts of Climate Change: Reflections From Malaysian Fishers. *SAGE Open* **2019**, *9*, 2158244019864204. [CrossRef]
19. Sukono, S.; Riaman, R.; Herawati, T.; Saputra, J.; Hasbullah, E.S. Determinant factors of fishermen income and decision-making for providing welfare insurance: An application of multinomial logistic regression. *Decis. Sci. Lett.* **2021**, *10*, 175–184. [CrossRef]
20. Sun, M.; Chen, B.; Ding, W.; Shi, G. A comparative analysis of factors influencing farm household income in disaster areas before and after natural disasters: The case of Wenchuan. *Tech. Econ.* **2010**, *29*, 88–92. Available online: http://www.cqvip.com/qk/80913x/201005/33954487.html. (accessed on 20 July 2022).
21. Lili, Y. *Research on the Impact of Natural Disasters on Chinese Farmers' Economy and Countermeasures*; Chinese article; School of Economics and Business Administration, Heilongjiang University: Harbin, China, 2007.
22. Zhang, H.; Du, X.; Zhuang, T. A study on the impact of natural disasters on the change of income sources of farming households —With the example of 650 farming households in poor ethnic areas of southwest China. *J. Sichuan Agric. Univ.* **2014**, *32*, 340–345. Available online: http://www.cqvip.com/qk/91109x/201403/662446237.html. (accessed on 15 May 2022).
23. Gao, Q.; Xu, H.; Yuan, B. Environmental change and fishermen's income: Is there a poverty trap. *Environ. Sci. Pollut. Res.* **2021**, *28*, 60676–60691. [CrossRef] [PubMed]
24. Crona, B.; Wassénius, E.; Troell, M.; Barclay, K.; Mallory, T.; Fabinyi, M.; Zhang, W.; Lam, V.W.; Cao, L.; Henriksson, P.J.; et al. China at a Crossroads: An Analysis of China's Changing Seafood Production and Consumption. *One Earth* **2020**, *3*, 32–44. [CrossRef]
25. Huo, X.; Liu, L.M. A study on China's OFDI influencing factors and the dynamic effect of economic growth: Based on principal component analysis and VAR model. *J. Zhejiang Gongshang Univ.* **2017**, *5*, 81–94.
26. Zhang, H.; Gao, S.; Zhang, Y. Corporate profitability forecasting based on principal component analysis and support vector machine. *Stat. Decis. Mak.* **2016**, *23*, 174–177.
27. Xie, Q.; Dong, X.-Y.; Yu, K.; Zhang, L.-Y.; Xu, Y.-H. Comprehensive Evaluation of Urban Economic Development in Yangtze River Delta Based on Cluster-Principal Component Analysis. *Complexity* **2021**, *2021*, 3328761. [CrossRef]
28. Zhou, Y.; Hou, S.J.; Zong, K. Ecological and economic benefit evaluation based on principal component analysis method. *Stat. Decis. Mak.* **2018**, *34*, 66–69.
29. Zhou, H.; Pang, J.R.; Wang, Z.Y. Study on measurement of financial systemic risk in China based on principal component analysis. *Insur. Res.* **2018**, *4*, 3–17.
30. Jollands, N.; Lermit, J.; Patterson, M. Aggregate eco-efficiency indices for New Zealand — A principal component analysis. *J. Environ. Manag.* **2004**, *73*, 293–305. [CrossRef]

31. Sands, G.R.; Podmore, T.H. A generalized environmental sustainability index for agricultural systems. *Agric. Ecosyst. Environ.* **2000**, *79*, 29–41. [CrossRef]
32. Ministry of Agriculture and Rural Affairs. *China Fisheries Statistical Yearbook*; Ministry of Agriculture and Rural Affairs: Beijing, China, 2011.
33. Cangelosi, R.; Goriely, A. Component retention in principal component analysis with application to cDNA microarray data. *Biol. Direct* **2007**, *2*, 2. [CrossRef] [PubMed]
34. Chhetri, B.B.K.; Larsen, H.O.; Smith-Hall, C. Environmental resources reduce income inequality and the prevalence, depth and severity of poverty in rural Nepal. *Environ. Dev. Sustain.* **2015**, *17*, 513–530. [CrossRef]
35. Daily, Z. *The Original Value and Worldwide Significance of Common Prosperity*; Economy and Information Technology Department of Zhejiang: Hangzhou, China, 2022. Available online: https://jxt.zj.gov.cn/art/2022/2/22/art_1229600053_58928225.html (accessed on 29 July 2022).
36. Jiyuan, W. On Narrowing the Gap between the Rich and the Poor and Building a Harmonious Society. *Chin. Politics* **2005**, *9*. Available online: http://www.cqvip.com/qk/83141x/200502/15848031.html (accessed on 29 July 2022).
37. Huibo, S.; Xia, Z. Quanty EvaIuation and Diversified Management Strategies of Rural Human Settlements in China. *J. Xian Jiaotong Univ.* **2019**, *39*, 105–113. [CrossRef]
38. Alamgir, S.; Furuya, J.; Kobayashi, S.; Mostafiz, R.B.; Ahmed, R. Farm income, inequality, and poverty among farm families of a flood-prone area in Bangladesh: Climate change vulnerability assessment. *GeoJournal* **2021**, *86*, 2861–2885. [CrossRef]
39. Angelsen, A.; Jagger, P.; Babigumira, R.; Belcher, B.; Hogarth, N.J.; Bauch, S.; Börner, J.; Smith-Hall, C.; Wunder, S. Environmental income and rural livelihoods: A global-comparative analysis. *World Dev.* **2014**, *64*, S12–S28. [CrossRef]