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The impact on food security and future adaptation under climate variation: a case study of Taiwan's agriculture and fisheries

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Abstract According to Food and Agriculture Organization and Intergovernmental Panel on Climate Change reports, climate change will lead to a severe food-supply problem. In the future, food production will continually decrease because of aggravated effects of climate change, causing food production to continually decrease. Food production will be unable to satisfy the demand of the global population, leading to a food-security crisis. As the world population continues to increase, the shortage of food will become increasingly severe, particularly for those located in "climate impact hotspots" of tropical, subtropical, small-island countries, and countries that are dependent on imports to meet domestic demand such as Taiwan. Numerous Taiwanese studies have suggested that agricultural and fishery productivity has declined because of climate variation, which may cause changes and instability in food quantity and quality, and increase deficiency and uncertainty in the food supply. Therefore, to discuss the risks posed by climate change to the stability of food supply and demand, this paper, taking Taiwan as a case, explored the impact of climate variation on food security and future adaptation strategies. TaiCCAT's supportive system for decision-making (TSSDA) was adopted here to assess and analyze the

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current situations of agricultural and fisheries production and supply, as well as future food supply risks, in addition to evaluating the deficiencies in the existing climate adaptation strategies in order to plan and revise feasible future adaptation alternatives. Based on the rule of risk management, the adaptation strategies recommended in this study were differentiated into two categories: proactive adaptation and planned adaptation. Proactive adaptation is emphasized to counter the uncertainty of food production, which increases the difficulty of production and necessity to import food. Conversely, planned adaptation can be used to manage the uncertainty of food supply to implement adjustments in production and marketing, as well as to mitigate the impact of climate variation.

Keywords Adaptation · Agriculture · Climate variation · Climate risk · Demand · Fisheries · Food security · Resilience · Risk management · TaiCCAT's supportive system for decision-making (TSSDA) · Supply

1 Introduction

The Food and Agriculture Organization (FAO 2009, 2014) and Intergovernmental Panel on Climate Change (IPCC 2014) indicated that climate change has influenced the global food production mode and resulted in severe food supply shortages. As the global food production mode has changed gradually under the effect of climate change (e.g., warming), global food production (e.g., cereal and marine fishery production) fluctuation and uncertainty are increased (FAO 2009, 2014; IPCC 2014). With the progress of time, food production technology continuously advances; however, it is limited to the finiteness of natural resources and the aggravation of climate change. This difficult condition, as Malthus (1789) noted in "An Essay on the Principle of Population," may lead to a point where food production is unable to meet the global demand in the future, initiating the potential problems of food shortages and starvation; thus, global food distribution will become more competitive, and there may be a food security crisis (FAO 2009, 2014; IPCC 2014). Therefore, if the existing food distribution mode is not improved, with the aggravation of climate change, the uncertainty of future food production is increased and food shortages will become more severe (Rice and Garcia 2011; OECD-FAO 2014).

The four elements of food security are supply, procurement, utilization, and stability, meaning everybody can obtain adequate, safe, and abundant nutritious foods through material, social, and economic methods at any time, thus, meeting and maintaining dietary requirements and food preferences for healthy life (FAO 2009, 2014). Taking the year 2012 as an example, within total global food production, agricultural production is 2.525 billion tons (maize, 877.9 million tons; rice, 734.9 million tons; wheat, 671.4 million tons; soybeans, 240.9 million tons), fishery production is 182.8 million tons (captured production, 92.4 million tons; aquaculture production, 90.4 million tons), and livestock production is 302.3 million tons (FAO 2014) (Fig. 1). In order to meet the global demand for food, the global food supply is continuously increased, especially crop and fisheries products, thus, the importance of food security steadily increases (OECD-FAO 2014). In the recent 50 years, global agricultural and fishery production have gradually increased (Fig. 1). While the production of the marine fishing industry of the global fishery industry has been saturated since the late 1980s, aquaculture fishery production continues to increase (Fig. 1b), meaning the importance and dependence of fisheries products for global food security increase steadily (OECD-FAO 2014;

FAO 2014). In 127 developing countries, fish accounts for 20% of animal protein intake, and fisheries products have become an indispensable food source for people to ingest calories, carbohydrates, and animal protein (FAO 2005).

Cereal is a staple food source for humans, and fish is an important source supplementing the required nutrient substances for humans (OECD-FAO 2014). In terms of demand for crop products, the consumption of edible cereals will exceed 1.2 billion tons in 2023, which is higher than the average level during 2011–2013 by 150 million tons. In the next decade, the wheat demand will increase by 12%, the rice demand will increase by 15%, and as the demand

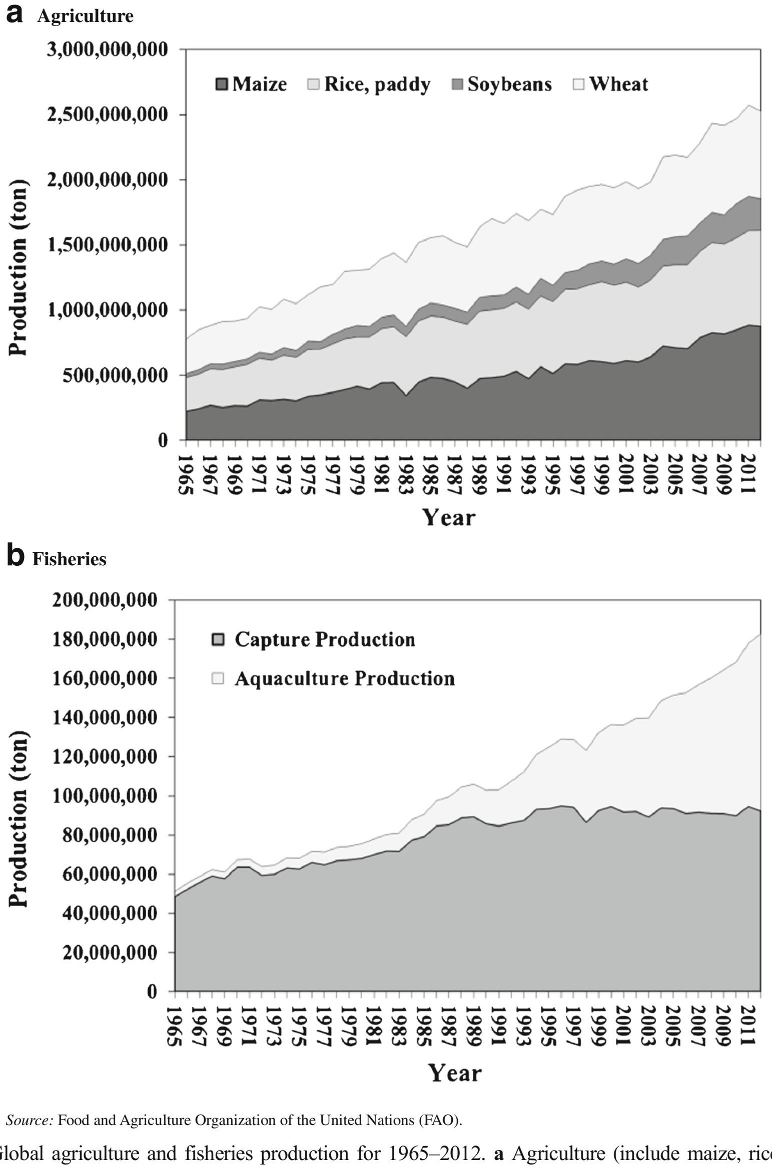


Fig. 1 Global agriculture and fisheries production for 1965–2012. **a** Agriculture (include maize, rice, paddy, soybeans, and wheat). **b** Fisheries (include capture and aquaculture production)

for vegetable oil and protein meal increases, oil seed will increase by 26% (OECD-FAO 2014). In terms of demand for fisheries products, the global demand for fisheries products will increase by 18% in 2022, while developing countries' demand for fisheries products will increase by 20%. The global demand for fisheries products will increase by 50% in 2050 (Rice and Garcia 2011; OECD-FAO 2014).

With the greater openness of international trade markets and the liberalization of global food and supply, global food trade has further developed in the direction of liberalization (FAO 2015). However, with the prevalence of WTO and global trade liberalization, the comparative advantage of agricultural and fisheries products becomes more apparent, and developing countries, where the production and labor costs are lower, have evolved as a key role in the global food supply chain (OECD-FAO 2014). The import ratio of agricultural and fisheries products has increased gradually in various countries since 1990, and replaced many countries' domestic production, becoming the main source of food supply and demand (FAO 2009). While this supply mode can enhance product diversification, it neglects production risks and uncertainty with various exporters. Thus, the food supply and demand market has a new "flaw" and climate change will expand and aggravate this flaw. National policy changes, economic fluctuations, production fluctuations, and environmental changes all have an effect on the quality and quantity of domestic production, causing food supply uncertainty and market fluctuations. Finally, these production fluctuations influence global food trade as well as the supply and demand market, and also directly or indirectly impact national food security via international trade (OECD-FAO 2014; FAO 2015). As the world gets warmer and extreme climate conditions increase, climate exerts aggravated effects on food production; as a result, global food production is faced with the severe test of natural disasters. In recent years, grave droughts and floods have incurred production reduction in grain-producing countries and sharpened the contraction of the world's food supply (IPCC 2014). The environmental fluctuation caused by climate change has influenced the food production mode severely and the production growth rate begins to decrease in some regions, influencing the stability of the future global food supply and demand (IPCC 2014).

Climate variation will adversely affect global agriculture, fisheries, and animal husbandry after 2030. Natural disasters caused by climate change will gravely impact food productivity security and lead to dramatic fluctuations and a drastic rise in food prices. The areas most affected will be in the developing countries which will suffer from severe hunger and poverty, and the countries which are heavily dependent on imports to meet domestic demands, such as many African nations, Singapore, Malaysia, and Taiwan (FAO 2014). For example, the 2007–2008 global food crisis came into existence with soaring food prices due to natural disasters, food shortage, and the export restrictions imposed by the world's major exporting countries. In 2007, the food prices on the international market increased by 23% compared to the previous year, 2006. Specifically, the prices of grain, edible oil, and dairy products rose by 42, 40, and 80%, respectively. The annual average prices of the three main agricultural crops (corn, wheat, and rice) were 164, 334, and 264/ton USD, 86, 62, and 12% higher, respectively, than those of the year 2000. This food crisis also caused food shortage in the countries dependent on imports to meet domestic demands, like Malaysia and Singapore. In the future, with the rise in international food market prices and the aggravation of such natural disasters as global warming, drought, and fresh water resource limitations, an insufficient food supply and dramatic food price fluctuations will become major challenges to the maintenance of global food security (FAO 2014).

In this developing trend, insular Taiwan, located in a subtropical zone with its food supply gradually becoming more dependent on imports to meet domestic demands, is also confronted with the same problem and impact as Malaysia and Singapore. In the domestic production, many studies have indicated the climate impact on Taiwan, and the effects are listed in Fig. 2. In Taiwan, the climate impacts on agricultural production include rainfall regime change, increased number of heavy rainfall, disease and insect damage type change, and soil loss and deterioration (Yao et al. 2000; Hsu et al. 2011; Hsieh 2012; Wang et al. 2013). The effects on fishery production include seawater warming, ocean acidification, increased frequency of debris flows, rainfall regime change, typhoon type change, and sea level rise (Hsu et al. 2007, 2011; Lu 2010; Wang et al. 2013; Chang et al. 2013; Igor and Lee 2014; Lu and Lee 2014; Ho et al. 2016). Under climate variation impact on existing food production, global warming has moved the suitable crop cultivating region northward, shortened the crop growth period, which has led to a decrease of production, and resulted in more frequent extreme climate occurrences, such as heavy rain, drought, extreme high temperature, extreme low temperature, and other disasters, thus damaging crops when they happen (Yao et al. 2000; Hsu et al. 2011; Hsieh 2012). The impacts on coastal and offshore fishery production include the disappearance of part of sedentary and migratory species, a change or going away of seasonable swimming habits, which leads to decreased fishery production, a change of composition of caught species, an imbalance of the ecological system, a change of fishing ground distribution, increased difficulties of fishing operation, etc. (Chang et al. 2013; Lan et al. 2014; Lu and Lee 2014; Ho et al. 2016). In terms of aquaculture fishery, the impacts produced by climate variation include the occurrence of debris flow, damage to culture water quality, shortage of aquiculture water caused by decreased rainfall, a decrease in the stability of marine fishery supply which has made the sources of fish meal and fish oil become unstable, etc. (Chang et al. 2013; Lu et al. 2012). Finally, the impact of climate variation will influence food security and the supply and demand market through domestic production and import (Fig. 2). The global climate impact not only incurs a food supply shortage but also indirectly

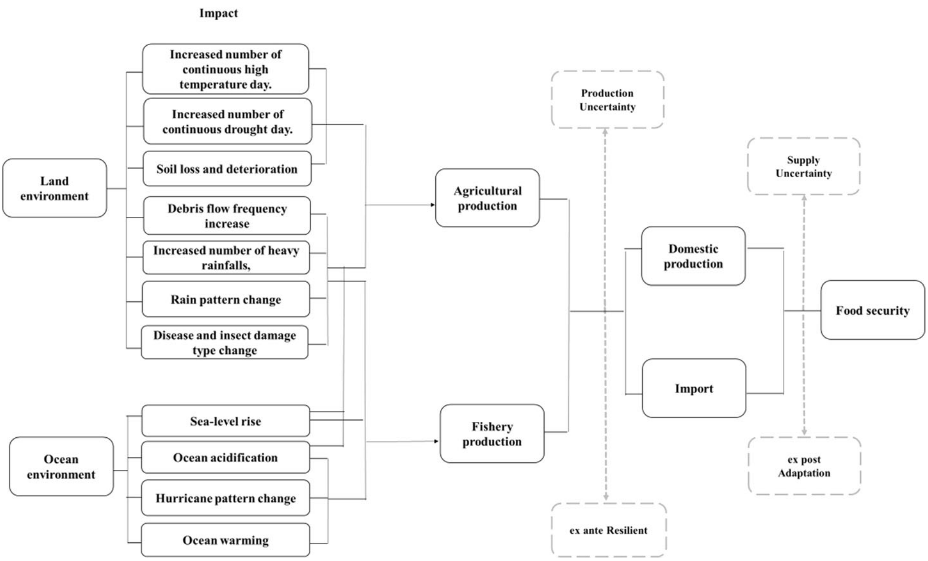


Fig. 2 Effects of climate variation on food supply and demand

affects Taiwan's food supply. For instance, when the 2007–2008 food crisis occurred, Taiwan, whose grain self-sufficiency rate was only 32%, barely survived the running-out-of-food crisis using the 3-month legal grain stocks. The prices of wheat, corn, and coarse cereals, which were almost 100% dependent on imports, continued to increase drastically, severely impacting the food processing industry and animal husbandry. With the aggravating climate variation and increasing uncertainty of production, supply, and demand, determining whether Taiwan has sufficient ability and adaptation measures to mitigate the impact of climate variation and enhance the resilience of the damaged industry will be the key to maintain food security.

In order to discuss the effect of climate variation on food supply, demand, and food security, this study, using Taiwan as the research subject, investigates the current domestic and foreign situations of agricultural and fisheries production and food supply, proposes feasible future adaptation strategies, targets the deficiencies in existing adaptation strategies, and provides strategic references for countries around the world, especially countries similar to Taiwan in geographical conditions and food supply patterns, to adapt to climate impacts. We use Taiwan's integrated research program on Climate Change Adaptation Technology (TaiCCAT) supportive system for decision-making (TSSDA) analysis (http://taiccat.ncu.edu.tw/intro/super_pages.php?ID=intro0) and discuss the following issues: (1) identifying problems of food supply and demand, and establishing objectives of food security; (2) assessing and analyzing the current risk of food supply and demand; (3) assessing and analyzing the future risk of food supply and demand; (4) identifying and assessing adaptation options for agriculture with fisheries in Taiwan; and (5) planning and implementing an adaptation pathway.

As climate variation mainly influences food supply and demand through its impacts on production and supply (Fig. 2), according to the risk management principle, facing such climate risk and uncertainty of food supply and demand, the production and supply adaptation strategy can be divided into prior preventive management and posterior compensatory management (UKCIP 2011; IPCC 2014). Therefore, the adaptation measures of this study will be discussed in two divisions. The uncertainty of production places emphasis on prior preventive management, and aims at the preventive measures of Avoidance, Transfer, and Reduction, in order to enhance the industrial toughness of production or import behavior. Supply uncertainty uses posterior compensatory management, where production and marketing are corrected and climate impact is mitigated through adaptive management and risk self-retention (UKCIP 2011; IPCC 2014).

2 Overview of agriculture and fishery sector in Taiwan

2.1 Demand and supply

Taiwan's food supply sources can be divided into crop products (47.76%), fishery products (21.07%), and livestock products (31.08%), as well as into Taiwan-made products and imported products (Food Supply and Utilization Yearbook 2014). According to the Food Supply and Utilization Yearbook of 2013, Taiwan's pure food supply is 12,933,000 metric tons. The food sources can be divided into 11 categories, including fruits (22.46%), greengrocery (18.80%), cereals (15.35%), meat (13.17%), aquatic products (6.34%), sugar and honey (4.63%), hulled seeds and oil seeds (4.33%), potatoes (4.27%), dairy products (3.88%), oil and fat (3.70%), and eggs (3.07%).

2.1.1 Demand

Crop products are the main source of human's staple food and calories, while fishery products provide bioelements of animal protein and carbohydrates for the human body, as well as the human Omega-3, which crop and livestock products are unable to supply (OECD-FAO 2014). Therefore, their importance for food security gradually increases (FAO 2014; OECD-FAO 2014).

According to the Food Supply and Utilization Yearbook of 2012, cereals are the main source of calories, especially rice and flour (Table 1), which provide 52% of the daily required carbohydrates. Meat and aquatic products are the main sources of animal protein, while cereals, hulled seeds, and oil seeds are the main source of vegetable protein. For example, the daily average calorie intake per capita was 2689 kcal in 2011, with 30.3% taken from agricultural products (Food Supply and Utilization Yearbook 2014). Fishery products are an important source of animal protein for Taiwanese. In the last decade, the annual supply volume of fishery products in Taiwan was about 820,000 tons. The animal protein provided by fishery products accounts for 36.18% of the total animal protein, 67.18 kcal, 2.5 g fat, and annual consumption per capita is about 39 kg (Table 1) (Food Supply and Utilization Yearbook 2014).

2.1.2 Supply

In recent years, under the effects of underproduction, westernized food habits, and comparative advantages, Taiwan's food supply and demand particularly emphasize imports, and dependence gradually increases (Fig. 3). Therefore, when discussing the effect of climate variation on food security, domestic and overseas food production and supply are of great importance, and subsequent analysis will be described according to the two parts. In terms of Taiwan's production, the main crop products are rice, wheat, soybean, and maize, and fishery products are supplied from four major fisheries, including long shore fishery, offshore fishery, aquaculture fishery, and deep sea fishery (Fig. 4; Fig. 5) (Agricultural Trade Statistics 2012; Fisheries Yearbook 2012; Food Supply and Utilization Yearbook 2014).

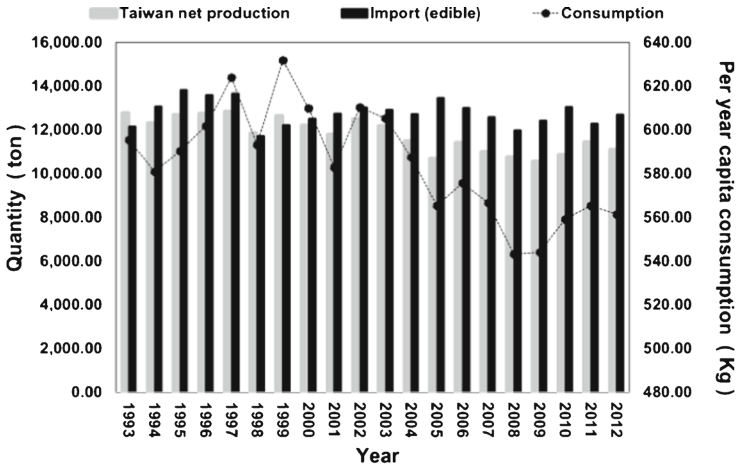
In terms of overall supply of crop products, the proportions of the four major foods (rice, wheat, soybean, and maize) to Taiwan's supply volume are rice, 106.9%; maize, 1.5%; wheat, 0.002%; and soybean, 0.001% (include statutory inventory). In terms of import side, the proportions are wheat, 104%; maize, 100.5%; soybean, 98%; and rice, 12.3% (include raw materials of processed products) (Table 2) (Food Supply and Utilization Yearbook 2012). Among the present four major food supplies, the rice self-sufficient ratio is higher (self-sufficient ratio = 100.4%), while maize, soybean, and wheat still depend on imports (self-sufficient ratio = 2.0%, 0.04%, 0.03%). While the import volume increases slightly, the import values of wheat, soybean, and maize increase gradually (Fig. 6a) (Food Supply and Utilization Yearbook 2012). At present, Taiwan's crop production structure is imbalanced and the country's food consumption composition includes staple food crops focusing on rice and wheat and fodder crops focusing on maize and soybean. Rice is currently a home-grown and self-sufficient staple food crop in Taiwan, but overproduction of rice is caused due to the insured purchasing policy. On the contrary, the supply of maize, wheat, and soybean are severely dependent on imports. In addition, the imbalance in proportion between home-grown grain crops and imported crops also exists in their consumption patterns. In the recent 10 years, the quantity of rice consumption produced in Taiwan has decreased progressively, while wheat consumption imported from abroad has continually increased. Thus, overall food import dependence has continually risen, while the agricultural trade deficit continues to deteriorate.

Table 1 Domestic supply, per day capita consumption, energy, fat, vegetable protein ratio, animal protein ratio, and food self-sufficiency ratio of agriculture and fisheries in Taiwan for 2000–2012

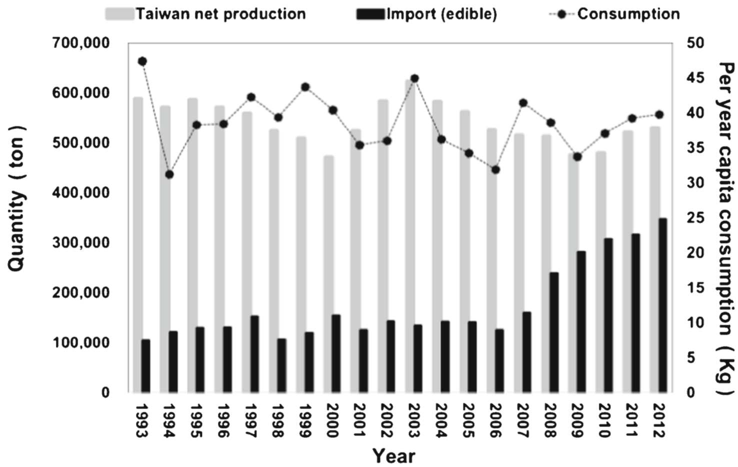
Year	Domestic supply (MT)		Per day capita consumption (g)		Energy (kcal)		Fat (g)		Vegetable protein ratio (%)	Animal protein ratio (%)	Food self-sufficiency ratio (%)	
	Crop produce	Seafood	Crop produce	Seafood	Crop produce	Seafood	Crop produce	Seafood	Crop Produce	Seafood	Crop produce	Seafood
2000	2304	100.18	1667	110.23	3010	73.00	123.48	1.92	96.23	24.94	35.4	129.50
2001	2238	89.50	1597	97.12	2867	68.58	116.98	2.25	92.00	22.43	34.6	141.30
2002	2296	92.35	1672	98.86	2920	72.66	124.38	2.42	94.85	22.43	35.6	142.90
2003	2291	101.14	1658	123.19	2962	86.21	124.78	3.24	96.13	24.65	34.1	141.40
2004	2239	81.81	1605	99.01	2882	65.51	119.98	2.55	91.94	20.30	32.1	146.53
2005	2205	77.68	1549	93.95	2941	67.04	126.55	2.99	91.57	19.30	30.2	158.15
2006	2258	72.67	1577	87.56	2816	53.34	118.41	1.75	90.08	18.21	32.1	163.62
2007	2223	94.69	1552	113.64	2837	68.33	119.08	1.95	92.02	24.26	30.3	147.72
2008	2123	88.47	1484	105.53	2634	68.37	107.52	2.38	84.51	23.34	32.2	136.06
2009	2137	77.69	1491	92.63	2737	58.17	111.64	2.00	86.84	21.41	31.7	124.63
2010	2171	85.39	1532	101.56	2754	68.34	115.22	2.70	88.25	22.58	31.3	122.58
2011	2183	90.90	1549	107.63	2739	75.68	111.70	3.15	89.67	23.19	33.9	126.33
2012	2204	92.59	1534	108.71	2797	74.51	115.24	2.79	89.48	23.66	32.7	122.06

Source: Food Supply and Utilization Yearbook, Republic of China (2012)

a **Crop produce**



b **Seafood.**

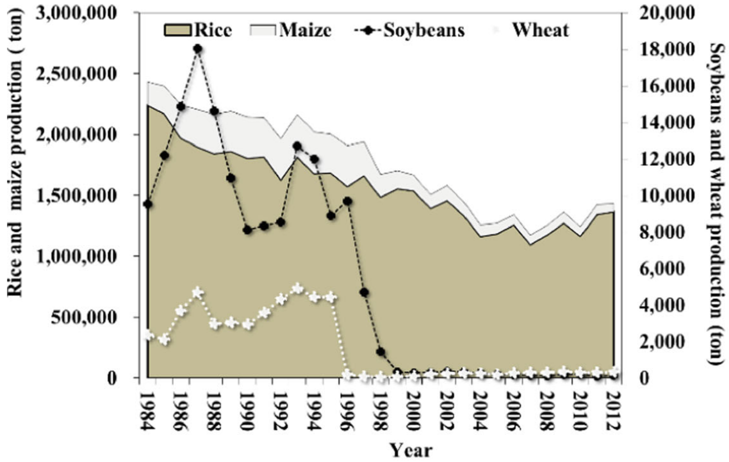


Source: Council of Agriculture (2012) and Fishery Agency (2012).

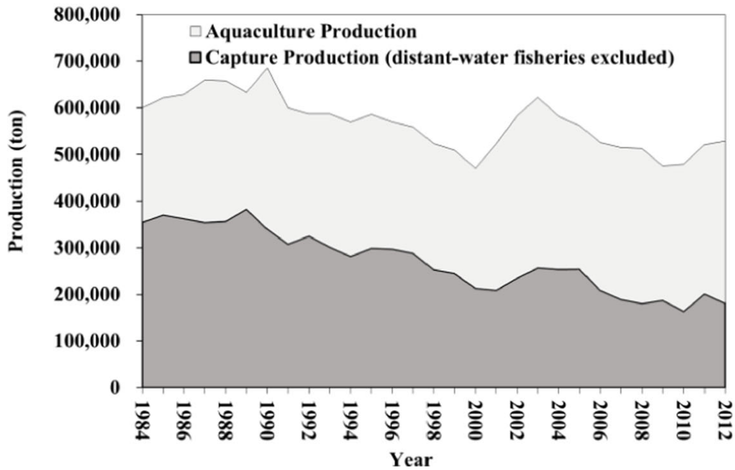
Fig. 3 Domestic production, imports production, and per day capita consumption of agriculture and fisheries in Taiwan for 1984–2012. **a** Crop produce. **b** Seafood

In terms of the overall supply side of fishery products, coastal and offshore fisheries and aquaculture account for about 57% of Taiwan's demand for fishery products (2012) (coastal and offshore fisheries account for 19.58%, aquaculture accounts for 37.58%). The import of fishery products accounts for 37% (2012), while deep sea fishery supplies about 5.33% of the domestic demand (2012) (Table 3), and the import ratio of fishery products gradually increases (Food Supply and Utilization Yearbook Republic of China 2012; Taiwan Fisheries Yearbook 2012). Coastal and offshore fishery production mainly correlates to the smaller size and scope of coastal and offshore fishing operations, which may easily cause the phenomenon of over-fishing. In recent years, the sea area has been polluted by industrial and commercial interests, severely damaging fishery resources and making it difficult to increase production. The existing problem of aquaculture fishing

a **Agriculture**



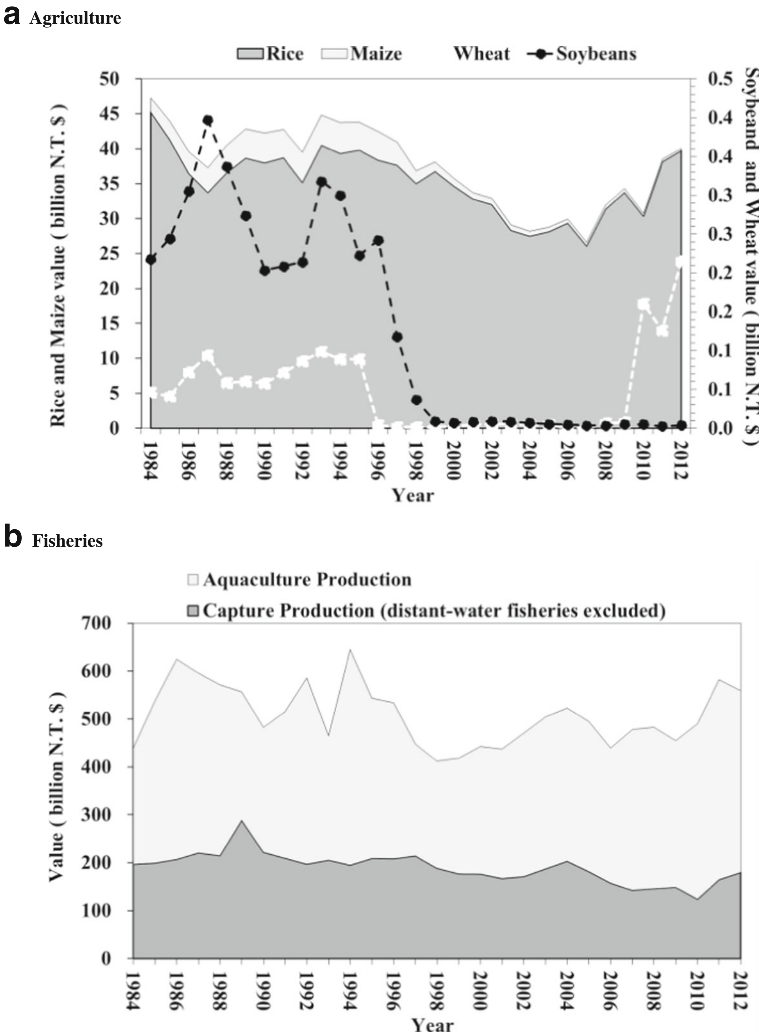
b **Fisheries**



Source: Council of Agriculture (2012) and Fishery Agency (2012).

Fig. 4 Agriculture and fisheries production in Taiwan for 1984–2012. **a** Agriculture (include maize, rice, paddy, soybeans, and wheat). **b** Fisheries (include capture and aquaculture production)

production is that after several years of culture, brackish-water culture is faced with land deterioration, coastal pollution, deterioration of water quality, and other pressures caused by coastal industrialization, so that aquaculture fishing production is now in an unstable state. Under the effects of underproduction, westernized food habits, and comparative advantages, Taiwan's seafood supply and demand now particularly emphasize imports, gradually increasing the country's dependence on the latter.



Source: Council of Agriculture (2012) and Fishery Agency (2012).

Fig. 5 Agriculture and fisheries production value in Taiwan for 1984–2012. **a** Agriculture (include maize, rice, paddy, soybeans, and wheat). **b** Fisheries (include capture and aquaculture production)

2.2 Domestic production

2.2.1 Agriculture

In the present food consumption of Taiwan, agricultural products are divided into dominant crops (paddy and wheat) and feed crops (maize and soybean). Taiwan is only self-sufficient in paddies at present, while wheat, maize, and soybean depend on imports (Agricultural Trade Statistics 2012).

Table 2 Ratio of domestic production of agriculture (include rice, maize, wheat, soybeans) products to imports in Taiwan for 2000–2012

Year	Domestic supply	Domestic production ratio				Import ratio			
	10,000 MT	Rice %	Maize %	Wheat %	Soybeans %	Rice %	Maize %	Wheat %	Soybeans %
2000	18,525	106.1	2.4	0.01	0.01	0.5	95.6	113	105
2001	18,050	100.4	2.2	0.02	0.02	0.5	101.5	97	114
2002	18,555	109.6	2.5	0.02	0.02	9.2	100.6	105	110
2003	18,413	100.7	2.2	0.02	0.01	13.1	102.0	104	103
2004	18,091	88.1	2.0	0.02	0.01	15.3	100.9	89	97
2005	17,785	89.3	1.8	0.01	0.01	6.3	103.9	103	104
2006	18,360	95.9	1.6	0.02	0.01	10.1	101.3	96	102
2007	17,879	84.2	1.6	0.02	0.01	12.4	92.1	103	99
2008	17,097	89.5	1.7	0.03	0.01	9.3	95.2	104	100
2009	17,259	98.9	2.0	0.03	0.01	8.0	101.7	106	105
2010	17,414	91.9	1.6	0.03	0.01	14.3	111.6	102	112
2011	17,465	108.2	1.8	0.02	0.00	10.6	96.0	105	106
2012	17,643	106.9	1.5	0.02	0.01	12.3	100.5	104	98

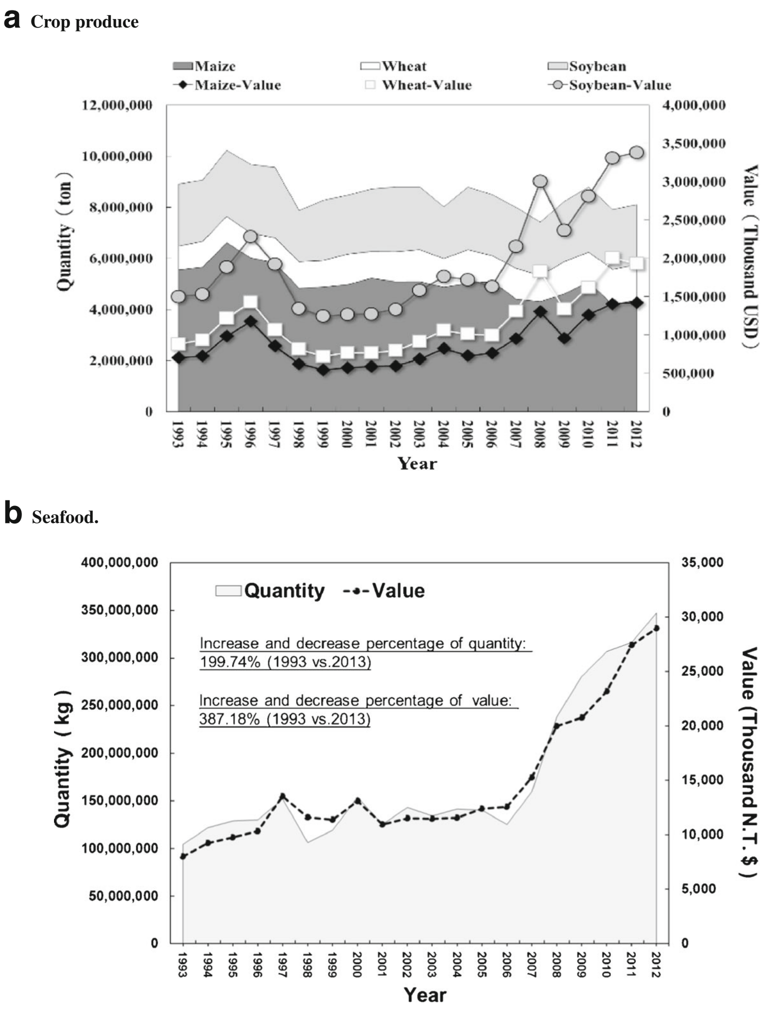
This table does not delete re-export ratio. Rice include statutory inventory. Maize, wheat, soybeans include raw materials of processed products. Source: Agricultural Trade Statistics (2012)

The paddy (*Oryza sativa* L.) is the dominant crop of Taiwan's agricultural production and is the most extensively planted cereal crop (Agricultural Trade Statistics 2012). The "Agricultural Statistics Yearbook" of 2012 shows that the rice cropping area is about 270,165 ha, the annual paddy production is 1.58 million tons, and the output value is NT$36.98355 billion. The feed maize cultivation area is about 8350 ha, the annual production of feed maize is 39,440 MT, and the output value is NT$354.958 million. The wheat cultivation area is about 2078 ha, the annual production of wheat is 4127 MT, and the output value is NT$129.12 million. The soybean cultivation area is about 470.5 ha, the annual production of soybean is 879 MT, and the output value is NT$439.6 million (Figs. 4a and 5a) (Agricultural Trade Statistics 2012).

2.2.2 Fisheries (coastal fishing and aquaculture)

Taiwan's capture fisheries within EEZ are classified into coastal fishery and offshore fishery. Production gradually increased from 60,000 tons in 1953 to the peak of 360,000 tons of 1989 (Fisheries Yearbook 2012). Due to rapid development and a lack of effective resource conservation measures, the growth of Taiwan's coastal and offshore fisheries production has been slowed since 1980 and even declined. Taiwan's coastal and offshore fisheries production has been maintained at about 200,000 tons since 1990 (Fig. 4b) (Fisheries Yearbook 2012). According to the statistics of the Fisheries Yearbook of 2012, the gross production of coastal and offshore fisheries was 201,696 MT, and the gross output value was NT$16.6334 billion. The gross production of longshore fishery is 28,117 NT, and the output value is NT$3.5912 billion (Figs. 4b and 5b) (Fisheries Yearbook 2012).

The aquaculture fishery is approximately divided into mariculture and inland aquaculture. As aquaculture and reproduction techniques are improved, aquaculture fishery production is greatly increased, and the aquaculture area is enlarged accordingly, thus, the growth is quite rapid. In 1990, Taiwan's aquaculture area was 76,281 ha and production was 341,453 MT. Aquaculture fishery production has been maintained at about 310,000 MT since 2001 and the



* This figure does not include nonedible crop produce and seafood.
Source: Council of Agriculture (2012) and Bureau of Foreign Trade (2012).

Fig. 6 Crop produce and seafood imports amount and value in Taiwan for 1993–2013. **a** Crop produce. **b** Seafood

annual output value increased from NT$26.9 billion (2001) to NT$41.7 billion (2012) (Figs. 4b and 5b) (Fisheries Yearbook 2012).

2.3 Import

2.3.1 Agriculture

According to the "Agricultural Trade Statistics", Council of Agriculture, Executive Yuan, 2012, crop products accounted for about 60% of Taiwan's agricultural product import volume. While there was no significant change in the import volume or makeup of the imports of crop products in the past 20 years, the import value began to increase greatly since 2006 (Fig. 6a) (Agricultural Trade

Table 3 Ratio of domestic production of seafood (include coastal fishing and aquaculture) to imports in Taiwan for 2000–2012

Year	Domestic supply	Domestic production ratio			Import ratio
	10,000 MT	Coastal fishing %	Aquaculture %	Offshore fishing (delete re-export ratio) %	%
2000	100.18	21.32	25.65	34.82	17.87
2001	89.50	23.40	35.05	25.21	16.73
2002	92.35	25.51	37.64	17.60	19.20
2003	101.14	25.43	36.14	22.81	13.28
2004	81.81	31.05	40.07	11.59	17.29
2005	77.68	32.78	39.58	9.58	18.06
2006	72.67	28.79	43.54	10.43	17.24
2007	94.69	20.04	34.33	28.77	16.86
2008	88.47	20.45	37.53	15.10	26.93
2009	77.69	24.19	37.01	2.69	36.11
2010	85.39	19.15	36.97	7.96	35.92
2011	90.90	22.19	35.12	7.88	34.80
2012	92.59	19.58	37.58	5.33	37.50

Source: Food Supply and Utilization Yearbook, Republic of China (2012) and Taiwan Fisheries Yearbook (2012)

Statistics 2012). The total import value was USD 92.4 billion in 2012. The main imported category is cereals and its products, followed by oil seeds and powder, while soybean, wheat, and maize of the two categories are the main foreign products (Fig. 6a) (Agricultural Trade Statistics 2012). Figure 6a shows that, while the import ratio of soybean, wheat, and maize is not markedly increased, the import value in 2012 was about doubled compared with that in 1993 (wheat, 190%; soybean, 134%; maize, 102%). This phenomenon indicates that, due to the price index and population growth, Taiwan must buy imported foods at higher prices, where wheat imports are mainly resulted from changing food habits, and maize, wheat, and soybean are imported as animal feed (Agricultural Trade Statistics 2012).

In terms of the changes in the importing countries, the U.S. was the main maize importing country before 2012; however, Brazil became the first importing country in 2012 and 2013. In the most recent 5 years, the U.S., Brazil, South Africa, Argentina, and India were major importing countries. In terms of soybean imports, the U.S. was the major importing country in latest decade; however, Brazil's import ratio increased since 2008, becoming an importing country equivalent to the U.S. in 2012. In terms of wheat, the U.S. has been the leading importing country to date, accounting for about 80% of the total amount of imports of wheat, while Australia is the second largest importing country (Table 4) (Agricultural Trade Statistics Tables 2007, 2008, 2009, 2010, 2012).

2.3.2 Fisheries

According to the "Statistics of Exports and Imports of the Republic of China," Bureau of Foreign Trade, Ministry of Economic Affairs, 2012, Taiwan's import volume of fishery products increased continuously since 2006 (Fig. 3b). Taiwan's import volume of fishery products was 300 million tons in 2013; the amount of imports of fishery products was 35 million (thousand NT$). The import volume and import value in 2013 were increased by 199.74 and 387.18%, respectively, as compared with that in 1993, meaning Taiwan's dependence on imported fishery products increases steadily (Fig. 6b) (Bureau of Foreign Trade 2012).

Table 4 Top 3 imports products of crop, top 3 imports country of each crop, and import proportion in Taiwan for 2007–2012

Unit: U.S. dollars, %

Year	Proportion of three crops in total value of the agricultural products imports		Crops	Rank	Countries	Countries	Proportion of imports
	Import value	Ratio					
2007	2,132,798	20.4	Corn, cereal	1	USA	923,607	97.86
				2	Argentina	12,831	1.35
				3	India	6153	0.65
			Soybean, oil seeds	1	USA	756,606	90.01
				2	Brazil	78,918	9.38
				3	Canada	3585	0.42
			Wheat, cereal	1	USA	333,826	95.80
				2	Australia	12,785	3.66
				3	Canada	1769	0.50
2008	2,966,916	24.5	Corn, cereal	1	USA	102,1752	79.58
				2	India	198,629	15.47
				3	China	45,005	3.50
			Soybean, oil seeds	1	USA	102,8383	87.48
				2	Brazil	102,001	8.67
				3	Argentina	38,853	3.30
			Wheat, cereal	1	USA	408,113	80.41
				2	Australia	94,912	18.70
				3	Canada	4456	0.87
2009	2,346,151	23.4	Corn, cereal	1	USA	786,671	82.67
				2	Brazil	123,244	12.95
				3	India	35,392	3.71
			Soybean, oil seeds	1	USA	749,328	72.91
				2	Brazil	273,875	26.64
				3	Canada	2077	0.20
			Wheat, cereal	1	USA	277,690	75.67
				2	Australia	73,335	19.98
				3	Canada	13,322	3.63
2010	2,759,889	21.6	Corn, cereal	1	USA	793,032	64.46
				2	Brazil	311,414	25.3
				3	Argentina	116,853	9.49
			Soybean, oil seeds	1	USA	727,044	61.33
				2	Brazil	401,840	33.9
				3	Argentina	52,237	4.40
			Wheat, cereal	1	USA	237,412	68.94
				2	Australia	91,701	26.62
				3	Canada	9169	2.66
2011	3,271,460	22.0	Corn, cereal	1	USA	881,301	63.74
				2	Brazil	334,454	24.19
				3	South Africa	70,070	5.06
			Soybean, oil seeds	1	USA	727,800	55.87
				2	Brazil	537,112	41.23
				3	Paraguay	27,006	2.07
			Wheat, cereal	1	USA	463,119	78.96
				2	Australia	109,379	18.65
				3	India	4477	0.76
2012	3,352,968	22.9	Corn, cereal	1	Brazil	706,893	50.13
				2	USA	362,581	25.71
				3	Argentina	213,745	15.15

Table 4 (continued)

Unit: U.S. dollars, %

Year	Proportion of three crops in total value of the agricultural products imports		Crops	Rank	Countries	Countries	Proportion of imports
	Import value	Ratio					
			Soybean, oil seeds	1	Brazil	719,341	49.73
				2	USA	713,919	49.35
				3	Canada	6487	0.44
			Wheat, cereal	1	USA	364,815	73.47
				2	Australia	105,083	21.16
				3	India	20,081	4.04

Source: Agricultural Trade Statistics Table (2007, 2008, 2009, 2010, 2012)

According to the statistical data of imported fishery products in 2011 (Table 5), Taiwan imports fishery products mainly from developed countries (U.S., Japan, Norway, Canada) and developing countries (Chinese Mainland, Vietnam, Indonesia, India, Thailand, Chile). The cephalopods import ratio is the highest (21%), followed by trout (19%), shrimp species (15%), and crucian (11%) (Bureau of Foreign Trade 2012). The main imported fishery products include grass shrimp, prawn, pomfret, salmon, oyster, cod, flatfish, cuttlefish, squid, scallop, and lobster. The volume imported from these countries exceeds 70% of the annual imports (Table 5).

3 Assessing and analyzing the current risk of food production and supply in Taiwan

Gradual climate variation and sudden changes result in changes in geographic environment conditions and the ecological structure (Hsu et al. 2011; IPCC 2014), which eventually influence food productivity and quantity (Brander 2007; Cochrane et al. 2009). The indirect effect of climate variation on social economy will interact with the direct effect on the environment and ecology, and the uncertainty and risk of the overall food supply chain are increased (Fig. 2) (FAO 2009, 2011; Rice and Garcia 2011).

3.1 Domestic production

3.1.1 Agriculture

Taiwan has a diversified weather environment due to its special geographic environment, interaction of completely different continental and maritime climate types, and steep landform (Hsu et al. 2011). However, the special environment and landform result in different types of meteorological disasters, thus, crop production processes are affected by different meteorological disasters (Yao et al. 2000; Hsieh 2012). According to the statistical data during 1981–2010, the annual agricultural loss caused by meteorological disasters was about NT$1–18 billion and such decrease of production resulted in sudden decrease of supply volume,

Table 5 Top 3 imported seafood species, import quantity, and ratio of the top 10 seafood-exporting countries to Taiwan in 2011

Unit: t, U.S. dollars, %

Countries type	Countries	Import value	Import quantity	Ratio	Number	Seafood species	Import quantity
Developed countries	Norway	76,075,870	15,297	11.70	1	Salmon	7474
					2	Mackerel	2585
					3	Trout	1052
	Canada	35,522,903	9730	5.46	1	Flatfish	3180
					2	Mackerel	1527
					3	Salmon	291
	USA	30,668,392	5961	4.72	1	Oysters	1051
					2	Cod	649
					3	Lobsters	290
	Japan	28,142,015	3490	4.33	1	Scallops	1366
					2	Salmon	795
					3	Conpoy	211
Developing countries	China	95,302,142	54,114	14.65	1	Squid	5218
					2	Crucian carp	4271
					3	Crab	3027
	Vietnam	51,464,123	27,587	7.91	1	Catfish	4080
					2	Grass shrimp	2568
					3	Prawn	1550
	Indonesia	46,475,064	22,855	7.15	1	Squid	1793
					2	Shark	1400
					3	Cuttlefish	1152
	Thailand	30,891,188	13,476	4.75	1	Prawn	4087
					2	Cuttlefish	2029
					3	Crucian carp	1853
	Chile	28,468,705	5841	4.38	1	Squid	1450
					2	Salmon	890
					3	Trout	200
	India	35,615,238	16,015	5.48	1	Pomfret	1044
					2	Cuttlefish	254
					3	Lobsters	184
Top 10 subtotal	458,625,640	174,372	70.53%	Import ratio of developed countries: 26.21%			
Other countries subtotal	191,830,275	59,161	29.47%	Import ratio of developing countries: 44.32%			
Total import quantity	650,455,915	233,534	100.00%				

This table does not include hydrophyte and nonedible fish. Source: Taiwan Fisheries Yearbook (2011)

thus, food prices rose high (Agricultural Trade Statistics Table 2010). The direct impact refers to the effect of meteorological disasters, such as typhoons, rainstorms, cold damages, drought, disease, pest damage, and wind damage, causing changes in crop-growing environments or mass mortality of plants, and production and productivity are reduced (Yao et al. 2000; Hsu et al. 2011; Hsieh 2012). For example, paddies were impacted by typhoons and torrential rains in the grain filling stage and harvest stage of 2010, the plants lodged, and the paddies failed to be harvested causing agricultural loss, and the loss accounted for over 90% of the total amount of paddy loss (Agricultural Trade Statistics Table 2010). The other meteorological disasters include drought in field preparation period before first cultivation season, cold damage to rice shoots, and disease and insect damage in the vegetative growth period. The average annual amount of paddy disaster loss in the past 30 years was about NT$800 million (Agricultural Trade Statistics Table 2010).

The change in rainfall regime will cause water shortage or drought, and even water resource allocation and scheduling problems (Hsu et al. 2011), which influence agricultural productivity and production (IPCC 2007, 2014). According to the findings of Tung (1997) regarding the Da-Cha River, in the climatic scenario of double CO_2, while Taiwan's total rainfall increased by 4%, the high-water period increased by 7%, and the low-water season decreased by 3%. From this, future rainfall is going to extremes. The rainfall will increase in the high-water period (summer), the runoff will increase, and the crops are likely to be damaged by precipitation (Tung 1997). On the other hand, the number of rain days decreases in the low-water season (winter), the temperature rise accelerates the evapotranspiration, and water resources become smaller. The irrigation water for northern paddy in the first cultivation season may be influenced by water shortage in winter (Yao et al. 2000; Hsieh 2012).

3.1.2 Fisheries (coastal fishing and aquaculture)

The impacts of climate variation on the capture fishery include (1) fishery distribution change and catch reduction: the fish species of Taiwan's capture fishery are closely correlated with the sea surface temperature (Cheung et al. 2013; Lan et al. 2014; Ho et al. 2016). As the sea water temperature around Taiwan rises continuously, the fish species that used to spawn and live through the winter southward recede northward, and the warm water fish species brought by the main and branch Kuroshio Current and South China Sea current expand northward (Ho et al. 2016). This trend may be aggravated as warming develops continuously in the future, resulting in complete isolation of these migrating populations or disappearance of local populations (Lu et al. 2012; Ho et al. 2014, 2016; Lan et al. 2014; Lu and Lee 2014); (2) effect of fishing operations: fishery displacement, resource changes, and the increased frequency and intensity of maritime storms increase the hazards to offshore operation safety, thus, the hazards in fishery work and fishery production costs are increased (Lu et al. 2012).

The direct impacts on fishery production include (1) sea-level rise results in seawater intrusion, which reduces the aquaculture area, and land salinization is more severe (Lu et al. 2012; Hsu et al. 2007); (2) extreme climate causes cold damage, changing the aquaculture environment or water quality, and causing sudden mass mortality of fishes (Chang et al. 2013); (3) typhoon and rainstorm cause debris flows, driftwood, and contaminants, severely destroying the water quality and environment of aquaculture ponds and coastal aquaculture sea areas (Hsu et al. 2007, 2011). The indirect impacts include (1) the reduction of rainfall results in less fresh water resources and fresh water aquaculture is confronted with greater challenges (Hsu et al. 2011; Lu et al. 2012); (2) fishery resources reduction impacts feed sources; (3) rising raw material prices increase fisherman cost outlay; (4) natural environment change is likely to change primary productivity, thus, increasing the morbidity and death rate of aquaculture species (Lu et al. 2012); (5) aggravated amplitude of fishery product price fluctuation; (6) fish oil and fish meal supply problems (Lu et al. 2012).

3.2 Major importing countries

The main food sources for Taiwan have changed from developed countries to developing countries (Tables 4 and 5), which gradually gain a position in food supply (Fig. 6) (Food Supply and Utilization Yearbook Republic of China 2012). However, the types of climate impacts on developing countries and developed countries vary with geographic location and environmental conditions. Therefore, developing and developed countries have different vulnerabilities and exposures to climate variation (Tables 6, 7, 8, and 9) (FAO 2015). In order to discuss the impact of climate variation, country types shall be classified to analyze the differences. The countries are divided into developing countries and developed countries in this study to discuss the current conditions of climate impact.

3.2.1 Agriculture

Among the major importing countries of Taiwan's crop products, the developed countries are the U.S., Canada, and Australia, which are mostly located in middle and high latitude temperate zones (Table 4). The climate risks of this type of countries include extreme climate impact (typhoon, drought, flood, extreme rainstorm, heat waves, and hail storm) and long-term climate impact (rainfall distribution or frequency change, ground temperature rise, annual precipitation reduction, and sea-level rise) (Table 6) (Motha and Baier 2005; Khakbazan et al. 2010; Antón et al. 2011), while the developing countries include India, Brazil, Argentina, and South Africa (Table 4). The climate risks on this type of countries include extreme climate impact (tropical cyclone, drought, flood, extreme rainstorm, heat waves, and hail) and long-term climate impact (rainfall distribution or frequency change, unstable rainy season, ground temperature rise, annual precipitation decrease, sea-level rise) (Table 6) (Mall et al. 2006; Midgley et al. 2007; Dufek and Ambrizzi 2008; Sharma and Sharma 2008; Blignaut et al. 2009; Gbetibouo and Ringler 2009; Galindo and De Miguel 2010; Peter Zhou et al. 2010). According to related literature, the two types of countries are confronted with different

Table 6 Climate impact types for the agriculture major product-exporting countries to Taiwan

Climate impact type		Developed countries			Developing countries				
		USA	Canada	Australia	India	Brazil	Argentina	South Africa	Taiwan
Extreme climate event	Tropical cyclone	●	●		●				●
	Drought	●	●	●	●	●	●	●	●
	Flood	●	●	●	●	●	●	●	●
	Extreme rainstorm	●	●	●	●	●	●	●	●
	Heat waves	●	●	●	●				
	Hail and ice storm	●	●				●	●	
Long-term climate impact	Rainfall distribution change	●	●	●	●	●	●	●	●
	Unstable rainy season				●			●	
	Rainfall frequency change	●	●	●	●	●	●	●	●
	Ground temperature rise	●	●	●	●	●	●	●	●
	Annual precipitation decrease			●	●			●	●
	Sea level rise			●	●		●	●	●

Source: Mall et al. 2006; Midgley et al. 2007; Dufek and Ambrizzi 2008; Sharma and Sharma 2008; Blignaut et al. 2009; Gbetibouo and Ringler 2009; Galindo and De Miguel 2010; Zhou et al. 2010

Table 7 Climate impact phenomena for the agriculture major product-exporting countries to Taiwan

Climate impact phenomenon	Developed countries			Developing countries				
	USA	Canada	Australia	India	Brazil	Argentina	South Africa	Taiwan
Soil moisture decreasing			•	•	•	•	•	
Irrigation water reduction			•	•		•	•	•
Change in pathogens and pest life-cycle and types	•	•	•	•	•	•	•	•
Plant lodging caused by strong winds	•	•		•				•
Hindrance to crop growth caused by extreme temperatures	•	•	•	•				•
Land degradation	•	•	•	•	•	•	•	•
Arable land reduction			•	•				•
Changes in alpine glacier and snow cover melting period	•	•		•				
Glaciers and snow cover reduction	•	•		•		•		
Physiological disorder of root respiration	•	•	•	•	•	•	•	•

Source: Mall et al. 2006; Midgley et al. 2007; Dufek and Ambrizzi 2008; Sharma and Sharma 2008; Blignaut et al. 2009; Gbetibouo and Ringler 2009; Galindo and De Miguel 2010; Zhou et al. 2010

climate impacts due to the different geographic locations. The meteorological disasters confronted by developed countries are high temperature and rain, whereas developing countries are confronted with high temperatures, a lack of rainfall, and more frequent extreme rainstorms (Tables 6 and 7).

Driven by comparative advantages in recent years, Taiwan's agricultural import mode has gradually transformed from developed countries to developing countries (Table 4). During 2007 to 2012, for the main imported agricultural products (include maize, soybean, and wheat), the exporting countries and their imports into Taiwan exhibit phenomenal growth and decline. For the import of maize, in 2007 the leading importing countries are the U.S. (97.86%), Argentina (1.35%), and India (0.65%); in 2012, the leading importing countries are Brazil (50.13%), the U.S. (25.71%), and Argentina (15.15%). For the import of soybean, in 2007, the leading importing countries are the U.S. (90.01%), Brazil (9.38%), and Canada (0.42%); in 2012, the leading importing countries are Brazil (49.73%), the U.S. (49.35%), and Canada (0.44%). For the import of wheat, in 2007, the leading importing countries are the U.S. (95.8%), Australia (3.66%), and Canada (0.5%); in 2012, the leading importing countries are the U.S. (73.47%), Australia (21.16%), and India (4.04%) (Table 4). However, due to the risk of climate variation faced by developing countries, including the long-term slow change in climate, shorter coastlines, or being located in impactive tropical zones or other geographical environment features, developing countries are faced with the negative impact and effect of extreme climate (Tables 6 and 7); in particular, the lag in production technology leads to a limited adjustment and adaptive capacity due to any climatic impact, and so production will decrease immediately and suddenly once an extreme meteorological disaster occurs (OECD-FAO 2014); this may also lead to an immediate reduction in exports, which have a great effect on Taiwan as it relies on imports to supply the domestic demand market (Figs. 3 and 6).

Table 8 Climate impact types for the top 10 seafood-exporting countries to Taiwan

Climate impact type		Developed countries				Developing countries						
		USA	Japan	Norway	Canada	Indonesia	Vietnam	India	Chile	China	Thailand	Taiwan
Extreme climate event	Hurricane	•										•
	Sea-level rise	•	•			•	•	•	•		•	
	Drought	•						•	•	•	•	•
	Floodwater						•				•	
	Cloudburst					•	•					•
Long-term climate impact	Rainfall change	•					•	•	•	•	•	•
	Ocean acidification		•								•	•
	Ocean warming	•	•	•	•	•	•	•	•	•	•	•
	Rain frequency change	•	•			•	•	•			•	•
	Saltwater intrusion		•			•	•				•	
	Water salinization			•		•	•					
	Ocean current change		•		•					•		•

Source: O'Brien et al. 2004; Rebolledo et al. 2005; Sepulveda et al. 2005; Lorentzen 2008; Estelle et al. 2009; FAO 2009; Vass et al. 2009; McIlgorm et al. 2010; Boateng 2012; Lu et al. 2012; Chang et al. 2013; IPCC 2014; Lan et al. 2014; Lu and Lee 2014

Table 9 Climate impact phenomena for the top 10 seafood-exporting countries to Taiwan

Climate impact phenomenon	Developed countries				Developing countries						
	USA	Japan	Norway	Canada	Indonesia	Vietnam	India	Chile	China	Thailand	Taiwan
Changes of fish migratory path	•		•		•		•		•		•
Coral bleaching		•								•	•
Increase of vulnerability on fish stock	•	•		•	•				•	•	•
Increase of warm water species	•	•							•		•
Suddenly increasing of single-species yield		•					•		•	•	•
Changes of coastal ecosystem	•	•			•				•	•	•
Changes of mangrove ecosystem					•					•	
Change of fishing season	•	•		•	•		•		•	•	•
Increase of difficulties on fishing operation	•	•	•	•	•	•	•	•	•	•	•
Increase of difficulties on prediction of fishing and oceanographic conditions lead more difficulties of fishery production		•		•	•						•
Aquaculture lower productivity			•		•	•	•				
Suddenly death of aquaculture fish				•	•	•			•	•	•
Change of aquaculture fish spawning quantity				•	•	•			•	•	•
Change of aquaculture fish spawning season		•		•	•	•			•	•	•
Deficiency of aquaculture water consumption	•				•	•	•	•	•		•
Reducing of aquaculture area					•	•	•			•	

Source: O'Brien et al. 2004; Rebolledo et al. 2005; Sepulveda et al. 2005; Lorentzen 2008; Estelle et al. 2009; FAO 2009; Vass et al. 2009; McIlgorm et al. 2010; Boateng 2012; Lu et al. 2012; Chang et al. 2013; IPCC 2014; Lan et al. 2014; Lu and Lee 2014

1. Developed countries

Table 7 shows the impacts of climate variation on developed countries, including environmental change and social economy. The impacts on natural environments include the changes in alpine glacier and snow cover melting period, heavy rainfalls that retard the physiological function of crop roots, and strong wind that causes plant dislodging and land degradation (Mall et al. 2006; Midgley et al. 2007; Dufek and Ambrizzi 2008; Sharma and Sharma 2008; Blignaut et al. 2009; Gbetibouo and Ringler 2009; Galindo and De Miguel 2010; Peter Zhou et al. 2010).

The developed countries are mostly located in middle and high latitude temperate zones. As air temperatures rose gradually in the temperate zone since the twentieth century, the rainfall has gradually increased, while the frost period has gradually shortened, meaning that the growing seasons were prolonged, and productivity and production were increased (e.g., U.S. and Canada) (Hatfield et al. 2011; Kurukulasuriya and Rosenthal 2003). While climate variation lengthens the growing seasons, it has adverse impact on agricultural production. As the alpine snow melting period is changed and irregular due to air temperature rise, the uncertainty of water source for agricultural production is increased, and agricultural production risk is increased (Table 7) (IPCC 2014). In addition to long-term change, extreme climate impact has a significant effect on the agricultural production of developed countries. For example, the crop yield of North America decreased significantly after the drought, extreme heat, and storms in 1999 (Motha and Baier 2005; Khakbazan et al. 2010). The great drought caused by high temperature and water shortage in the U.S. in the summer of 2012 resulted in a great decrease in maize and soybean yields, and caused a global food crisis (Mallya et al. 2013). As heat waves and great droughts occurred more frequently and severely in Australia due to rainfall reduction and air temperature rise, the production of wheat was influenced (Khakbazan et al. 2010; Barlow et al. 2014; Collet 2014). In the future, as extreme climate occurs more frequently, crop production will be confronted with greater fluctuation and uncertainty. In addition, as the air temperature and humidity rise, disease and pest damage has gradually shifted and expanded toward high latitudes (Gregory et al. 2009) (Table 7).

2. Developing countries

The leading exporting countries (India, Brazil, Argentina, and South Africa) of agricultural products into Taiwan are all developing countries (Table 4). The developing countries are mostly located in the tropical or rainless regions of hot zones of climate impact (Hobday and Pecl 2014). The local air temperature has approached the critical value of suitable temperature, the response to air temperature rise is sensitive, and there are intrinsic problems of unequal allocation of national resources and poverty, thus, this type of country has higher exposure and vulnerability than developed countries (OECD-FAO 2014; IPCC 2014; FAO 2015). The impacts on natural environments include soil moisture decreasing, irrigation water reduction, changes in pathogens, pest life-cycles, types, and land degradation (Table 6) (Lal 2003; Midgley et al. 2007; Gregory et al. 2009; Galindo and De Miguel 2010). As rising air temperature increases the evapotranspiration rate and uncertainty of seasonal rainfall, crops cannot obtain adequate water when they grow, thus, reducing yield and even killing the crops (Dufek and Ambrizzi 2008). Himalayan and Andean glaciers shrank due to air temperature rise, and these water sources may be reduced in the future. A sudden extremely high temperature can cause glacial lake outburst floods or soil erosion, which damages agriculture (Sharma and Sharma 2008; Rabatel et al. 2013). In addition to long-term change, the increase in the frequency and intensity of extreme climate events causes the reduction of crop yield and quality, and even the mass mortality of plants **(**Table 7**)**. For example, the monsoon pattern is changed due to climate variation in India and South Africa, and the rainfall pattern is irregular, causing meteorological disasters, such as large-scale drought or flood disaster, which render agricultural operations more difficult, and local crop yield is influenced (Cook et al. 2004; Mall et al. 2006; Midgley et al. 2007). For example, the tropical cyclone on the east coast of India, and the hail in South Africa and Argentina caused heavy agricultural losses. In addition, the sea-level rise confronted by countries with short coastlines (e.g., India) also resulted in soil salinization of farmland and reduction of farmland quality and arable land (Lal 2003).

3.2.2 Fisheries (coastal fishing and aquaculture)

Taiwan imports fisheries mainly from the developed countries of the U.S., Japan, Norway, and Canada, which are important fishery food exporting countries (Table 5). According to related literature, the climate risks of this type of country include extreme climate impact and long-term climate impact (Table 8) (Tian et al. 2004, 2006; McIlgorm et al. 2010; West and Hovelsrud 2010; Tian et al. 2011; Griffis 2012). Among the major countries where Taiwan imports fisheries, the developing countries include the Chinese Mainland, Vietnam, Indonesia, India, Thailand, and Chile, which are important fishery food exporting countries (Table 5). The climate risks on this type of country includes ocean warming, sea-level rise, freshwater salinization, changes in air temperature and rainfall distribution, typhoon, flood, and drought (Table 8). In addition, developing countries are mostly located in the hot zones of climate impact or countries with short coastlines, where climate impact is severe (Conway 2012; FAO 2014).

1. Developed countries

The impacts on natural environments and ecology include fish migration route change, coral bleaching, increased fish line group vulnerability, increased warm water species, marine ecology changes, etc. (Tables 8 and 9). For example, oceanic warming causes changes in fishery resources and fish school structures in Japan. Many warm water fish species, such as anchovy, mackerel scad, and red oceanic squid, have increased markedly (Tian et al. 2004, 2011). The occurrence of warm water fish species has increased gradually since the 1970s and regime shifts have occurred (Tian et al. 2006, 2011; Kawasaki 2013). The location of salmon spawning was changed due to seawater warming and ocean current changes in Canada, and the population abundance and migration route of salmon were changed (McIlgorm et al. 2010).

The natural environmental impacts on the aquaculture fishery of developed countries include productivity reduction, sudden death of aquaculture fishes, spawning period changes (Arctic Climate Impact Assessment 2005; Lorentzen 2008; McIlgorm et al. 2010). For example, climate warming has caused sudden death and productivity reduction of the salmon aquaculture in Norway and Canada, and the frequency increased as climate variation was aggravated (Tables 8 and 9) (Lorentzen 2008; McIlgorm et al. 2010).

2. Developing countries

The climate impacts on the developing countries can be divided into natural environmental and social impacts. Natural changes include increased warm water fishes, sudden increases in single species, changes in coastal ecology, changes in fishing seasons, and coast erosion (Tables 8 and 9). For example, the yield of marine fishery has decreased gradually under the effect of climate variation in India, and the geographic location of warm water fish species has shifted (Table 9) (O'Brien et al. 2004; Vass et al. 2009). The vulnerability of local marine organisms of Thailand is increased, and the nutrition order of local fishery resources of Thailand has shifted (Table 9) (Estelle et al. 2009). Climate variation has decayed the local fertility of the ocean in Chile (Rebolledo et al. 2005), and such ocean environment change will impact the humanistic community (e.g., disordered fishing season, increased operation difficulty level, increased fishing, and oceanic predictions difficulty level), which will render fishery production more difficult (Table 9).

The impacts on the aquaculture fisheries of developing countries include reduced aquaculture area, inadequate water supply, and reduced productivity, thus, the production of aquaculture fishery has been influenced (Tables 8 and 9). The impact of climate variation will increase the mortality of aquaculture fishes and reduce aquaculture productivity (Tables 8 and 9) (Boateng 2012). In Indonesia and India, climate variation has gradually reduced aquaculture production and damaged aquaculture facilities (Tables 8 and 9) (O'Brien et al. 2004; Vass et al. 2009). A shortage of water for aquaculture results in problems for aquaculture fishery production in Chile (Sepulveda et al. 2005).

3.3 Effect of climate impact on importing countries on Taiwan's food supply stability

While total food supply has not changed a lot in the past 10 years (Tables 2 and 3), among the food supply composition the proportion of imported agricultural and fishery products has showed a rising trend (Tables 2 and 3; Fig. 3) (Agricultural Trade Statistics 2012; Food Supply and Utilization Yearbook 2012; Food Supply and Utilization Yearbook Republic of China 2012; Taiwan Fisheries Yearbook 2012). This phenomenon indicates that the food supply in Taiwan places an increasingly high reliance on imported food. Therefore, as agricultural and fisheries products highly depend on import for domestic demand, any changes in production mode, and strong fluctuations of the production of various importing countries, can directly influence Taiwan's food supply and demand market, and may impact several other aspects, including (UN-DESA 2009; IPCC 2014; OECD-FAO 2014)

1. When the food exports of offshore food-producing countries are affected or fluctuations occur in exported food prices due to changes in their own economy, policy, climate impact, and other issues, food security and supply stability will decrease. For instance, in 2007, the rise of international grain prices triggered the global food crisis, and the leading grain export country canceled its export subsidy, levied an export tax, restricted and banned exports, and implemented other close-door policies, in order to maintain its own food supply and demand.

2. In the future, influenced by climate variability or extreme climate, a change in production mode and a reduction in production in every exporting country could possibly lead to a change in the future global food distribution model (Rice and Garcia 2011; IPCC 2014; OECD-FAO 2014; FAO 2015). With the trend of a continually increasing global population, developing countries will have higher demand for food in the future, especially China and other developing countries that exhibit rapid population growth (OECD-FAO 2014). In the future, exporting countries' export ratio may be affected or their exports may drop due to greater domestic market demand or a negative fluctuation in production. If Taiwan wants have sufficient offshore food, then it may be required to buy offshore food at higher costs in order to maintain its food security and supply.
3. Food importing countries cannot master or control climate risk, climate impact, and the adjustments faced by food exporting countries (OECD-FAO 2014). The exporting countries are required to deal with the problems or adjust production and prices by themselves. Therefore, the excessive dependence of its food supply on imports will result in inadequate food security, which is limited by these exporting countries.
4. If a sudden reduction in offshore food supplies occurs caused by extreme climate impact, and international market trade decreases dramatically, then the serious fluctuations in market volume and prices may directly impact food supply chain as well as the stability of its food supply and demand market, causing a food security crisis. For instance, in 2012, maize and soybean production in the U.S. suffered from a significant reduction due to high temperatures and drought in the summer. Thus, any insufficiency in the international market supply can cause a global food crisis.

4 Assessing and analyzing future risk of food supply with demand

As Taiwan is located in a subtropical zone of a hot zone of climate impact (Hobday and Pecl 2014), and it is an insular region with a short coastline, the climate impact type is similar to developing countries (Table 6, 7, 8, and 9). Climate impact will influence food supply and demand due to its vulnerability and exposure (IPCC 2014; FAO 2015). In terms of import, with the changes in Taiwan's production conditions, food habits, and the drive of comparative advantage, the demand and dependence of Taiwan's food supply and demand on imports gradually increase (Fig. 3, Table 2). In the most recent 20 years, Taiwan's agricultural import value increased gradually (wheat, 190%; soybean, 134%; maize, 102%), and the import volume and value of fishery products increased by 199.74 and 387.18% (Fig. 6) (Food Supply and Utilization Yearbook Republic of China 2014). However, whether the increasingly globalized international trading market can steadily supply our food will be the key to food security, especially at the present time, when the global environment is confronted with climate variation and climatic anomalies (IPCC 2014; FAO 2015).

Due to the principle of comparative advantage, developing countries with low production costs have evolved as the main body of the global trading market (OECD-FAO 2014). The trends in Taiwan are consistent with those of many countries (such as Singapore, Malaysia, and Iceland), as Taiwan imports food mainly from developing countries (Table 2). Its ratio of food imports has gradually increased (Figs. 3 and 6). Therefore, the developing countries' climate impact and supply capability will have considerable effect on the food supply chain (Tables 4 and 5) (FAO 2009, 2015). Take Taiwan's major importing countries for example. Developing countries have higher exposure and vulnerability than developed countries, as they are mostly located in the hot zones and face the climatic impact in tropical and subtropical zones. As most of these countries have a short coastline or are island countries, their type of climatic impact is composite (Tables 7, 8, and 9) (Hobday and Pecl 2014) and the impact of climate variation is direct and profound (Conway 2012; FAO 2014). In addition to common climate impacts, in comparison to developed countries, developing countries are confronted with the real-time effects of extreme climate events (e.g., extreme rainstorm) and direct climate impacts (e.g., sea-level rise and drought) (Tables 6, 7, and 8). However, as it is limited by geographic and environmental conditions, the adaptation capability for climate variation is limited. The impact of climate variation influences the local environment and ecosystem, which is reflected in the supply and demand of the overall industry (Fig. 2, Tables 7 and 9).

As the international trading market becomes increasingly globalized, this risk not only restricts developing countries' food production, supply, and demand, it also significantly influences and threatens the countries depending on imports to supply the domestic demand market, which can cause problems in global food security, especially the countries that are dependent on imports to meet domestic demands (FAO 2015). Taking the 2007–2008 global food crisis for example, the rise in global food prices caused a global food security crisis mainly because the grain-exporting countries (such as Cambodia, Thailand, Indonesia, and Egypt) issued a rice export restriction policy. The grain-importing countries were forced to purchase grain at a higher price in the market, so the food prices remained high. According to the World Bank's investigation, the prices of wheat and food in the international market rose by 181 and 83% on the whole, respectively, between 2006 and 2008. The main cause of the food crisis was natural disasters and the dramatic global increase in food consumption. Due to this food crisis, the food prices soared and the citizens were under threat of food insecurity in many developing countries, especially the Southeast Asian countries. For instance, Malaysia, because of insufficient rice production, mainly imports rice from Thailand or Vietnam. In the second half of 2007, Vietnam initiated a ban on rice exporting, which increased the price of Thailand's rice threefold in Malaysia.

5 Identifying and assessing adaptation options of agriculture with fisheries in Taiwan

In the face of aggravating climate variation and the uncertainty of domestic and offshore food production, supply, and demand, determining whether Taiwan has the capability and sufficient adaptation measures to mitigate the impact of climate variation and enhance the resilience of the damaged industry will be the key to maintaining food security.

In Taiwan, in answer to climate variation, Taiwan governmental bodies created related adaptation strategies for various industries. According to the "National Program of Action on Climate Change," the agricultural production adaptation strategies comprise four major aspects, while fishery production has five major aspects (National Development Council 2012). The agricultural production adaptation strategies include (1) building a food security system according to the degree of risk; (2) integrating technologies to enhance industrial stress resistance; (3) building a multi-objective and sustainable high-quality forestry business adaptation model, and pushing green forestation; and (4) building monitoring and evaluation systems for agricultural weather and domestic and foreign market changes. The fishery production adaptation strategies include (1) assisting fishermen to adjust their fishery management mode, (2) rational utilization of ocean resources, (3) building an early warning system for disasters, (4) mastering the effect of climate variation on fishery production and prices, and (5) strengthening integration of production and marketing (Table 10) (National Development Council 2012). However, the existing adaptation strategies for agriculture and

Table 10 Existing agricultural and fishery production adaptation strategy of action on climate variation in Taiwan

Type	Adaptation strategy	Risk management			
		Prior preventive management[a]			Posterior compensatory management[a]
		Avoidance	Reduction	Transfer	Adaptive management and risk self-retention
Agricultural production	Building a food security system according to the degree of risk	●	–	–	No
	Integrating technologies to enhance industrial stress resistance.	●	–	–	
	Building a multi-objective and sustainable high-quality forestry business adaptation model, and pushing green forestation	●	–	–	
	Building monitoring and evaluation systems for agricultural weather and domestic and foreign market changes	–	●	–	
Fishery production	Assisting fishermen to adjust their fishery management mode	●	–	–	No
	Rational utilization of ocean resources	–	●	–	
	Building an early warning system for disasters	●	–	–	
	Mastering the effect of climate variation on fishery production and prices	–	●	–	
	Strengthening integration of production and marketing	–	●	–	

[a] The adaptation measures are based on the "National Program of Action on Climate Change" of the central government announcement. Based on the rule of risk management, the adaptation strategies were differentiated into two categories: proactive adaptation and planned adaptation. Source: National Development Council (2012)

fisheries are mainly preventive adaptation measures, which reduce the effect of climate variation through three adaptation modes, avoidance, transfer, and reduction, in order to enhance the industrial toughness of Taiwan's production and import. Compensatory management after climate variation remains insufficient (National Development Council 2012). With the aggravation and normalization of extreme climate change, immediate posterior compensatory management becomes increasingly important to resolve the influence of climate on food production.

In the domestic production, the Taiwan has had its own share of extreme climate events, such as Typhoon Morakot, chilling injury in Peng-hu, etc. The frequency of extreme climate events has gradually become normalized (Hsu et al. 2011; Lu et al. 2012; Chang et al. 2013). Taking typhoons as an example, in the past 40 years, violent typhoons have gradually increased in frequency. During 1979 and 1999, extremely heavy rainfall occurred once every 3–4 years (Hsu et al. 2011). During 2000 to 2009, extremely heavy rainfall and typhoon took place on average once a year. These extremely heavy rainfall and typhoon events have often caused severe economic losses and disasters (Hsu et al. 2011). Extreme climate change causes an immediate production reduction in the global market. In times of global food shortages and dramatic rises in food prices, grain-exporting countries might issue a policy to restrict or ban exports to ensure domestic food security and curb inflation. For example, during the global food crisis in 2007, Thailand, Indonesia, and Egypt restricted rice exports to ensure their domestic food security. Thus, a running-out-of-grain crisis may occur in the countries that depend on imports to supply their domestic markets. If there is no appropriate management for immediate industrial correction and adjustment to enhance industrial elasticity, it is likely to cause heavy economic losses (FAO 2009; OECD-FAO 2014). Therefore, in answer to the effect of climate variation on food supply, climate adaptation measures shall be considered more comprehensively and completely in the future, in order to minimize the impact of climate variation to guarantee food security.

6 Planning and implementing adaptation pathway

As Taiwan's food supply mode gradually evolves from the previous one of self-sufficiency to the current one that depends on imports to meet domestic demand, climate variation adaptation has to be planned holistically in two aspects: local production and overseas imports. Taiwan's local production is aimed to improve productivity of agriculture and fisheries, reduce dependence on imports, and further confirm food supply sources. Meanwhile, the imported food supply is controlled and food sources are guaranteed through overseas investment, international trade cooperation, etc. The complementary methods of local and overseas production can mitigate potential risks. The food supply can be stabilized by diversified development, extensive cooperation, and long-term planning.

6.1 Mitigating uncertainty of production

In order to mitigate unknown, but actually existing, climate impacts, the future production adaptation strategy shall place emphasis on preventive management, where climate risk and impact are mitigated by the preventive measures of policy making, adjusting the industrial scale, developing alternative schemes of imported products, and spreading import risks through the adaptation methods of avoidance, transfer, and reduction, in order to enhance the industrial toughness of production and import behavior to increase the overall resilience of industry, while reducing vulnerability and exposure (Fig. 7) (Brander 2007; Daw et al. 2009; FAO 2009; Lu et al. 2012; Rice and Garcia 2011; IPCC 2014).

The domestic and overseas production conditions and their environmental and industrial structures are different. Thus, the adjustment strategy and planning direction in production we have used herein are also different. For the part of domestic production, the governmental sectors and producers can make good use of the country's geographical and environmental advantages to adjust production and industry behavior according to any differences in the sources of climate risk, degree of effect, and impact level upon the country. Thus, the impact and degree of effect of climate variation on domestic production can be minimized. Take Taiwan as an example, the Taiwan's geographical position stretches across various latitudes and its southern and northern parts have different geographical conditions, environments, and air temperatures (Hsu et al. 2011; Lu et al. 2012; Chang et al. 2013; Lan et al. 2014). Therefore, we can evaluate the environmental conditions in an existing agricultural usage area or fishery operating area by means of space planning, as well as evaluate the fitness and environmental changes in the existing usage areas under future climate variation by means of a weather simulation model, so as to find the suitable production method and phase (Rice and Garcia 2011; IPCC 2014). For instance, in agriculture, we can make use of a crop change or rotation system to avoid an unsuitable farming environment and to increase crop yields (Yao et al. 2000; Hsieh 2012). In fishery, there can be an adjustment made in the fishing operating period and scale as well as in fish varieties, etc. in order to mitigate the effect of climate impact

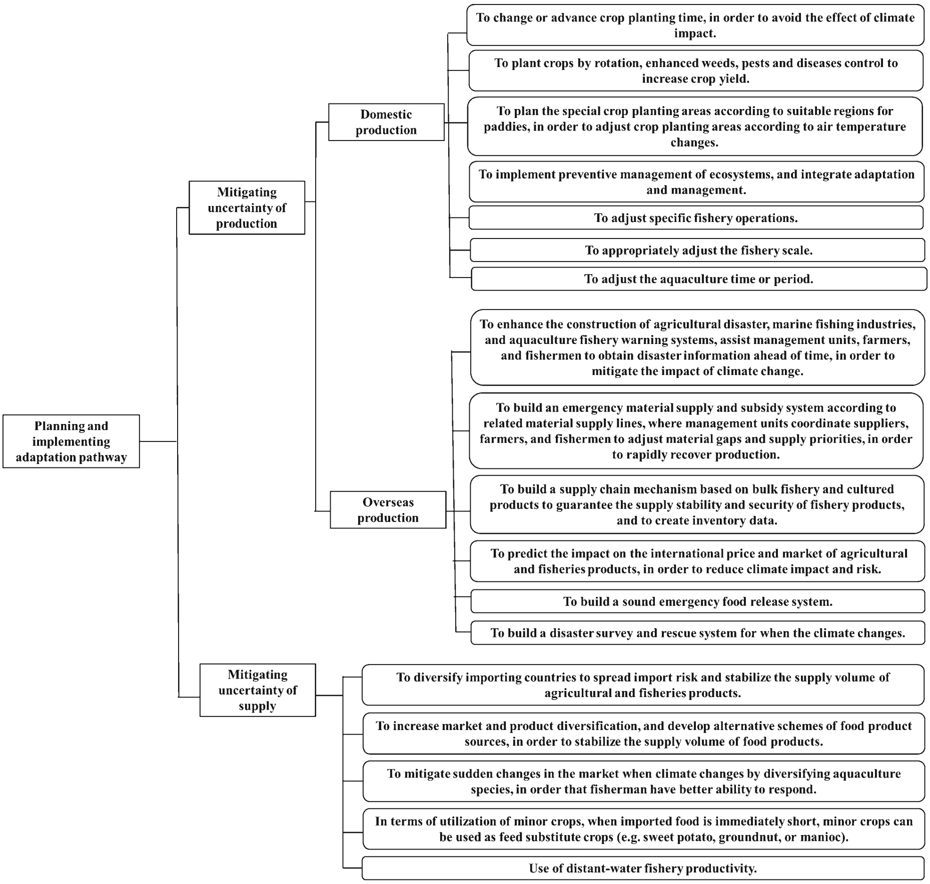


Fig. 7 Adaptation strategy for food produce, supply, and demand uncertainty and risks induced by climate variation

on marine fishery production (Lu et al. 2012; Ho et al. 2016). In aquaculture, Taiwan can make use of its special geographical condition to execute long-distance aquaculture and other adjustment methods, so that species in different life stages can inhabit a suitable aquiculture area to increase their survival rate (Lu et al. 2012; Chang et al. 2013). The main adaptation strategies include

1. To change or advance crop planting time, in order to avoid the effect of climate impact (Fig. 7).
2. To plant crops by rotation; enhance weed, pest, and disease control to increase crop yield (Fig. 7).
3. To plan the special crop planting areas according to suitable regions for paddies, in order to adjust crop planting areas according to air temperature changes (Fig. 7).
4. To adjust specific fishery operations, including changing the catch target, implementing fishing off season, and changing the operation water area for adaptation, in order to mitigate the impact of climate variation on the fishery or fish species (Fig. 7) (Daw et al. 2009; Lu et al. 2012).

5. To appropriately adjust the fishery scale, enhance the exit mechanism of fishery participants, and continue to buy fishing boats, in order to maintain appropriate fishery scales to reduce the overfishing pressure of coastal and offshore fisheries, recover fishery resources, and effectively promote sustainable utilization of fishery resources (Fig. 7) (FAO 2009; Lu et al. 2012).
6. To implement preventive management of ecosystems and integrate adaptation and management (Fig. 7) (Daw et al. 2009; FAO 2009; Lu et al. 2012).
7. To adjust the aquaculture time or period, in order that the fishes evade unfavorable aquaculture environments by stepwise aquaculture, in order to increase the survival rate (Fig. 7) (FAO 2009; Lu et al. 2012; Rice and Garcia 2011).

In terms of overseas production, the main adjustment strategy is to reduce the possible impact degree and effect on food supply and demand when overseas production decreases sharply and when there are drastic fluctuations or sudden production reduction in overseas production due to climate variation. Taiwan must rely on a food adaptive system and urgently release food reserves to timely stabilize prices in the domestic market. A robust food early warning system is thus necessary to rapidly respond to the variation in overseas production and provide relevant information to the government, in order to formulate appropriate adjustment measures. However, based on the adjustment policy in the agricultural and fishery industries in its national policy program, Taiwan's food early-warning system and urgent adjustment measures are extremely scarce at present (Table 10) (National Development Council 2012). This will be an important and key factor influencing Taiwan's food security and whether it has the sufficient ability to reduce any climate impact, or will its food supply chain suffer from this risk. Therefore, future agricultural management shall enhance the agricultural disaster warning system, build an emergency material supply and subsidy system, and build disaster survey and rescue systems. Fishery management shall enhance the early warning system, and establish a fishery supply chain mechanism and market forecast to reduce fishery production uncertainty and climate risk (Figs. 2 and 7) (UKCIP 2011; IPCC 2014). The main adaptation strategies of mitigating uncertainty of import food production:

1. To enhance the construction of agricultural disaster, marine fishing industries, and aquaculture fishery warning systems, assist management units, farmers, and fishermen to obtain disaster information ahead of time, in order to mitigate the impact of climate variation (Fig. 7) (Chang et al. 2013).
2. To build an emergency material supply and subsidy system according to related material supply lines, where management units coordinate suppliers, farmers, and fishermen to adjust material gaps and supply priorities, in order to rapidly recover production (Fig. 7) (IPCC 2014).
3. To build a disaster survey and rescue system for when the climate variation; where the first issue is to survey the disaster location and area and the degree of disaster loss and rescue range are accurately mastered by using satellite images and land survey data, in order to rapidly reduce disaster loss (Fig. 7).
4. To build a supply chain mechanism based on bulk fishery and cultured products to guarantee the supply stability and security of fishery products, and to create inventory data (Fig. 7) (FAO 2009; Lu et al. 2012; Rice and Garcia 2011).
5. To predict the impact on the international price and market of agricultural and fisheries products, in order to reduce climate impact and risk (Fig. 7) (IPCC 2014; OECD-FAO 2014).

6.2 Mitigating uncertainty of supply

The uncertainty of supply occurs after production uncertainty and is a supply stability problem caused when food production is reduced by external or internal factors (Fig. 2). During 1993 to 2012, Taiwan's agricultural and fishery products mainly focused on imports from some countries (Tables 4 and 5) (Taiwan Fisheries Yearbook 2012), and the ratio of imports has gradually increased (Fig. 6) (Council of Agriculture 2012; Bureau of Foreign Trade 2012). The importance of imported food to Taiwan's food supply has gradually replaced domestic production (Fig. 3) (Council of Agriculture 2012; Fishery Agency 2012). However, due to the excessive reliance on one food variety or one importing country, Taiwan's food supply and demand change according to the export or supply model in these countries (Tables 4 and 5) (Taiwan Fisheries Yearbook 2012), causing frequent shortages of food supplies in Taiwan's domestic market and a decrease in food supply stability. The future food product supply strategy shall not focus on a specific product, or depend on one, or a few, specific countries excessively, and different countries' products shall be used as substitute products. Through the control of domestic and overseas food supplies, the guarantee of overseas investment and the establishment of a food fund, the impact of climate can be positively influenced to a certain extent (Figs. 2 and 7) (UKCIP 2011; IPCC 2014). The main adaptation strategies include

1. To importing countries, increase market and product diversification, and develop alternative schemes of food product sources, in order to stabilize the supply volume of food products (Fig. 7) (FAO 2009; Lu et al. 2012). Taking Singapore as an example, the Singaporean government formulated a food security plan to diversify its food sources, optimize local product production, and minimize the potential risks that Singapore is faced with due to its heavy dependence on food imports, through an effective food delivery system, diversified development, extensive cooperation, and long-term planning.
2. To mitigate sudden changes in the market when climate variation by diversifying aquaculture species, in order that fisherman have better ability to respond (Fig. 7) (Lu et al. 2012; Chang et al. 2013).
3. To enhance "food self-reliance" in answer to uncertain, but actually existing food crisis and climate risk, the import of agricultural and fisheries products shall not be the main source of food supply and demand in the future (Fig. 3, Tables 2 and 3); and productivity and competitiveness of domestic agricultural and fishery industries shall be enhanced, in order to enhance Taiwan's food self-reliance, in order that the uncertainty and risk of climate impact and food supply can be diversified more effectively (Fig. 7) (Lin 2014).
4. In terms of utilization of minor crops, when imported food is immediately short, minor crops can be used as feed substitute crops (e.g., sweet potato, groundnut, or manioc). These crops are applicable to Taiwan's climate and are tolerant of disaster adversity, meaning the cropping system has been operated for years and production is stable (Fig. 7).
5. Use of distant-water fishery productivity: in Taiwan's overall fishery product supply, the tuna production from distant-water fishery have a relatively low domestic sales ratio, meaning most of the catches are directly exported, and their contribution to Taiwan's fishery supply is low (Table 2). The coastal and offshore fishery sector is still the main source of providing fish for Taiwan's demand and for maintaining food security. However, due to under-production in Taiwan, the proportion of imported fish has gradually increased, while the self-supply ability of local fishery products has gradually decreased. If it can be effectively planned and brought into Taiwan's fishery product supply and

demand market in the future, the fish catch species of offshore fishery can be set as the alternative fishery products. The climate impact and risk can be effectively diversified, in order to enhance Taiwan's fishery food self-reliance (Fig. 7). When the volume of supply decreases sharply in the international fishery trading market, it is necessary to rely on the supply of alternative fishery products to rapidly resume the original balance point between supply and demand. At present, in addition to the incorporation of fish catch species of offshore fishery as alternative fishery products (squid and saury), the government can also consider incorporating more fish catch species as adjustable fishery products imported from overseas in the future. Moreover, one certain fish catch species of offshore fishery production can be set as alternative fishery products of overseas import.

6. To build a sound emergency food release system, which is an important mechanism for providing an adequate supply volume when extreme climate events occur, requires that the food stock be increased, and a food priority support agreement signed with adjacent countries under a system of regional cooperation to reduce the crisis of short-term food shortage (Fig. 7) (IPCC 2014; FAO 2015).
7. The domestic and overseas food supply is controlled and food sources are guaranteed by overseas investment and the establishment of a food fund. For example, Singapore announced in 2009 that the Agri-Food and Veterinary Authority would establish a food fund and co-develop overseas food sources. The fund was mainly used in regard to the food primarily needed in people's lives, such as rice, fish, meat, and vegetables. This fund comprised two parts: the diversified food fund and the food productivity development fund. The former emphasized investing and developing food regions, diversifying food sources, alleviating the potential risks arising from heavy dependence on food imports, and ensuring sufficient supply. The latter aimed to increase the volume of domestic production by financially supporting research and development.
8. Expanding connections: apart from engagement in WTO multilateral negotiations, there should be an active effort made to sign the FTA with different countries to help drive economic and trade liberation and expand the international market. In addition, the FTA signing could deepen connections with such advanced and main foreign capital source countries like the U.S., European countries, and Japan.

7 Conclusions

In the early stages, food trade had high variability, and performed short-term regulation and supplementation in the food supply chain. In recent years, with the liberalization of international trade and the drive of comparative advantage, the importance of imported foods for agricultural and fishery supply, demand, and food security gradually increases, and become the key to supply and demand stability. Developing countries, where production and labor costs are relatively low, have gradually occupied a position in the international fishery products trading market. Taiwan, Singapore, and Malaysia have experienced a similar trend in which the importance of imported foods has gradually increased in relation to their food supply. This could supplement the food demand and enhance product diversification, but may also result in uncertain production and supply, creating problems in the food supply chain. The global climate impact will expand market flaws and the influence is profound. The study results show that, in comparison to developed countries, developing countries are confined to geographic location and environment, meaning their vulnerability and exposure under the impact of climate variation are higher and the uncertainty of production is increased. Finally, climate risk and the uncertainty of production, as confronted by developing countries, will be transferred to various countries with trade liberalization to increase the importance of global food trade, causing concerns about global food supply and demand stability and food security. Therefore, in order to reduce the uncertainty of food supply and demand and climate risk, there must be appropriate adaptation strategies in the future, in order to mitigate the effect of global food trade market liberalization. In the future, we should adapt measures of production and supply simultaneously to adjust to the climatic impact. The mitigation of food production uncertainty shall place emphasis on preventive management in the future, in order to enhance the toughness of domestic production and import behaviors by making management policies, adjusting industry, developing alternative schemes for imported agricultural and fisheries products, and diversifying production uncertainty and risk through the preventive measures of avoidance, transfer, and reduction, in order to enhance the overall industrial resilience and reduce vulnerability and exposure. Supply uncertainty shall be eliminated by the actions of posterior compensatory management to promptly alleviate the impact resulting from extreme climate change, reduction in international trade markets or export restrictions implemented by grain-exporting countries, where production and marketing are corrected and handled by adaptive management and risk self-retention.

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