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How do livelihood assets affect the environmental sustainability of shrimp farming? A case study in Tra Vinh province, Vietnam.

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ABSTRACT

This study is based on the DFID's sustainable livelihood framework, which lists five types of capitals to analyze the current status of shrimp farmers' livelihood assets: human capital, natural capital, physical capital, social capital, and financial capital. The data collected were based on addressing 300 shrimp-farmer households in 2019 in Tra Vinh province through questionnaire interviews and transect walks. The study was conducted to estimate the effects of five forms of livelihood capitals and 17 indicators on the environmental sustainability of shrimp farming measured by 19 criteria. Results revealed that, three forms of livelihood capitals and five indicators had statistical significance affecting the environmental sustainability of shrimp farming in Tra Vinh. In addition, it was found that using groundwater in shrimp farming was not environmentally sustainable. Conversely, having reservation ponds had a positive impact on environmental sustainability.

INTRODUCTION

The shrimp industry is facing a serious environmental problem. According to **MARD (2015)**, the degree of pollution in rivers was 2.5 to 3 times the permitted standard. Though 80% of surveyed shrimp farmers recognised the problem, but, because of the high profits in the shrimp industry, shrimp farmers seemed short sighted when it comes to environmental responsibility. They have been ignoring the effects of certain prohibited chemicals sometimes used in shrimp farming in spite of well-known regulations and environmental protection laws. Moreover, small-scale farms are popular in Tra Vinh province, as they utilise land for shrimp ponds, but they do not have reservation ponds. Hence, wastewater is directed to rivers or canals, a state that leads to pollute water resources. Thence, a vicious cycle occurs when farmers use that polluted water for new crops; it is a big risk for disease outbreaks. According to the Aquaculture Department of Tra Vinh province, the shrimp farming industry has suffered significant damage and loss in recent years. In 2019, there were 6,238 shrimp farming households damaged with

2,121ha of shrimp farming losses due to drought, fluctuation of temperature, and epidemic diseases. These losses accounted for 19% of the total shrimp farming area excluding extensive production.

Obviously, environment plays a crucial role in aquaculture in general, and it seriously affects the shrimp industry. Shrimps are highly sensitive to adverse environmental changes, such as quality of water, degree of salinity, the temperature of water, and pH degree (**Kongkeo & Phillips, 2001**). In shrimp farming, water resources are considered a "common pool," which is used free of charge. Hence, the quality of the water resource is dependent on the farmer's behavior or environmental perception when it comes to resource management. In fact, aquaculture cultivation has been facing increasingly severe instances of polluted surface water due to directly discharge without proper treatment. However, in order to continue their work, the majority of farmers used groundwater to supplement shrimp ponds during the crop. In other words, the farmers transfer the common resource to private resource. Overexploitation of groundwater sooner or later would lead to subsidence issues, which exacerbate flooding and seawater intrusion inevitably. By the year 2017, approximately two million wells extracting 2.8 million m^3/day of groundwater in Mekong Delta were established, in which Tra Vinh accounted for 88,833 wells and exploited 224,773 m^3/day (**Bui *et al*., 2017**). Groundwater exploitation is the main cause of subsidence in the Mekong Delta, Vietnam. Its average rate of subsidence was about 1.1 cm annually over the past 25 years, and this trend is likely to increase in the near future (**Minderhoud *et al*., 2017**).

In Vietnam, the brackish shrimp farming industry has brought large profits for farmers in recent years. In fact, this industry has been developing since 1980 (**EASRD, 2006; MARD, 2015**). It was cultivated across the north and south of Vietnam, especially in the Mekong Delta, where it accounted for 91% (699,725 hectares) of national shrimp farming land in 2014, with an average growth rate of 3.12% per year from 2010 to 2014 (**MARD, 2015**). In 2018 shrimp productivity in the Mekong Delta accounted for nearly 83% of the total national shrimp production, with an average growth rate of 8.85% per year from 2010 to 2018 (**GSO, 2020**).Tra Vinh province is precisely one of 12 provinces in Mekong Delta suitable for brackish shrimp cultivating with a 65km coastal line and a dense system of rivers and canals. In addition, **Decision 784/QD-UBND** of Tra Vinh province dated 27 April 2018 'Developing shrimp farming industry to 2025', has planned to develop shrimp production based on the natural condition of each area. While, the intensive and semi-intensive methods should continually develop and apply new technology in farming without abusing chemicals or antibiotics. Going forward, it will be mandatory to acquire a certificate showing that farmers are meeting the exporting market requirements. Additionally, the extensive shrimp farming industry should combine its resources to preserve the existing mangrove forests and help balance the ecosystem.

All the aforementioned problems pose challenges to sustainable shrimp farming in terms of environment. Therefore, this study was presented to compare the current status of livelihood assets of three shrimp farming systems and find out how livelihood assets affect the environmental sustainability of shrimp farming in Tra Vinh province.

MATERIALS AND METHODS

Literature reviews

There are several definitions of sustainability that depend on the perspective of each author or institution. But there is some general agreement on particular points. In general, sustainability concerns three important pillars: economic, environmental, and social development (**Valenti *et al*., 2011; Chowdhury *et al*., 2015**). And to achieve sustainability, first the human race must alleviate poverty and ensure food security without exhausting natural resources (**DFID's Sustainable Livelihoods Approach and its Framework**). For example, sustainable development utilizes all present resources without compromising future generations' livelihoods (**Barbier, 2016**). Therefore, in this study, the environmental sustainability of shrimp farming implies that the shrimp industry has to maintain a balance between extracting natural resources and preserving them for their posterity. However, to measure sustainability, both qualitative and quantitative methods were employed by some authors when it came to finding suitable indicators. **Chowdhury *et al.*** (**2015**) addressed water quality, soil quality, and biodiversity loss to measure sustainability by the quantitative method. Furthermore, sustainability combines with other economic and social institutional dimensions to gauge what constitutes sustainable shrimp farming. While **Valenti *et al.*** (**2011**) suggested a quantitative method to measure environmental sustainability in aquaculture with three indicators—natural resources, efficiency of natural resource use, and generated waste. The qualitative method is based on the list of improved environmental criteria for sustainable shrimp aquaculture to assess the impacts of shrimp farming on the environment (**Noennback, 2002**). Both methods worked perfectly for their respective purposes. However, they still did not present the final value of the environmental sustainability of aquaculture cultivation. This study is also based on the environmental sustainability criteria of those authors and experts' opinions to establish the list of criteria for the environmental sustainability of shrimp farming (Table 6). Additionally, the final value of environmental sustainability was normalized on an individual basis.

Study area

Tra Vinh province is located in the northwest Mekong Delta, Vietnam, between $9^0$31'46''N-$10^0$4'5''N latitude and $105^0$57'16''E -$106^0$36'04" E longitude, belonging to 12 provinces of the Mekong Delta. It has quite plain geographical features and an elevation above sea level of approximately 1 meter. It also has a 65km coastline. The annual average temperature is from 26°C to 27.6°C, and the annual average precipitation is about 1,520 mm. The average annual humidity is 84%, and annual total hours of sunshine reaches 2,556 hours. Tra Vinh lies between the Co Chien and Hau rivers, which flow from the Mekong River. Inland, there is a dense network of rivers and canals across the province, comprising nine natural rivers and 12 related tributaries, as well as an immense number of artificial canals serving agriculture and aquaculture. It has a total area of 2,341 km^2, a population of about 1,009,168 in 2019, and a density of 443 people per km^2 (**G°SO, 2019**).

Household survey

The survey was conducted to interview 300 households in total. Households were selected randomly by each member of the team who was assigned to concentrate on a certain number of households for each village. This survey was repeated for each village until the process was completed. The interviewing team had two members, and each member had to complete four surveys per day. The study started at the beginning of December 2018 and finished at the end of January 2019. There were 320 samples in total, after omitting uncompleted samples or illogically answered samples, there were 300 total samples for this study.

Analyzing current status of livelihood assets of shrimp farmers

The study analyses the current status of livelihood assets affecting strategies of sustainable shrimp farming. The livelihood assets based on the DFID's sustainable livelihood approach and its framework which has five types: human capital, natural capital, physical capital, social capital and financial capital. Data were based on the conception of livelihood assets, the experts' discussion, characteristics of local shrimp farming, and actual fieldwork. Additionally, 17 indicators were found for five livelihood assets to measure the value of each type of livelihood capital (Appendix A).

Because each of the original value of indicators was calculated in different units or scales, they first would be normalized on the rating scale from 0 to 1 as the equation (1) if an indicator has a positive relationship with its type of livelihood capital (**Vincent, 2004; Hahn *et al.*, 2009; Urothody *et al*., 2010; Antwi-Agyei *et al*., 2013**), otherwise using equation (2) for a negative relationship with its type of capital (**Rajiv Pandey *et al*., 2017**).

$$\mathbf{I_{ij} = (X_{ij} - min\ X_{ij}) / (max\ X_{ij} - minX_{ij})} \qquad \mathbf{(1)}$$

$$\mathbf{I_{ij} = (Max\ X_{ij} - X_{ij}) / (max\ X_{ij} - minX_{ij})} \qquad \mathbf{(2)}$$

Where $\mathbf{X_{ij}}$ is original value of indicator jth of the livelihood capital $\mathbf{i^{th}}$. The ith is human capital, natural capital, physical capital, social capital and financial capital.

$\mathbf{I_{ij}}$ is the normalized average value of indicator $\mathbf{j^{th}}$ and the livelihood capital $\mathbf{i^{th}}$.

min $\mathbf{X_{ij}}$ is the minimum value of indicator $\mathbf{j^{th}}$ and the livelihood capital $\mathbf{i^{th}}$.

max $\mathbf{X_{ij}}$ is the maximum value of indicator $\mathbf{j^{th}}$ and the livelihood capital $\mathbf{i^{th}}$.

Then, value of each livelihood capital **(C_i)** is the average of all indicators of types of capital.

$$C_i = \sum_{j=1}^{n} \left(\frac{I_{ji}}{n} \right) \qquad (3)$$

Value of C_i from 0 to 1.

Equation (3) shows that the weight of each indicator is equal, which means every indicator in each capital has an equal degree of importance and influence. This approach has been employed in studies such as **Sulliva *et al*.** (**2002**) **and Eakin *et al*.** (**2008**).

Analyzing the effect of livelihood assets on the environmental sustainability of shrimp farming

The study estimated the impact of livelihood assets and the indicators on the environmental sustainability of shrimp farming. This study used linear regression for analysis as follows:

$$Y_i = \alpha + \beta_k X_{ki} + \mu_i$$

Y_i is the environmental sustainability of shrimp farming that was measured by the list of criteria (Table 6). Y_i is calculated by the number of "yes" answers dividing the total number of criteria, so its value is from 0 to 1. According to **Roennback** (**2002**), defining the regional and global criteria for environmental sustainability in shrimp aquaculture, and expert opinions, 19 criteria related to environmental sustainability of shrimp farming were selected as shown in Table (6).

X_{ki} represents explanatory variables: they are the five types of capitals (human capital, natural capital, physical capital, social capital, and financial capital) for the first regression and second regression with 17 indicators. They were calculated due to the above equations and mentioned in Appendix A.

RESULTS AND DISCUSSION

The survey was conducted to interview 300 households in total and divided into three sample groups: intensive (195 samples), semi-intensive (62 samples) and extensive production (43 samples).

Current status of livelihood assets of shrimp farmers

Human capital

The age range of the shrimp farmer households surveyed in this study ranged from 24 to 66 years old, whereas 56.67% were over 46 and 43.33% were under 45. Therefore, average years of experience (H3) in shrimp farming was seven years, and only 10% of shrimp farmers had more than 10 years' experience. Regarding the 30-year history of the Vietnamese shrimp industry, the average years of experience of Tra Vinh shrimp farmers are quite modest. However, it is assumed that seven years is enough time to learn how important the role of the environment in shrimp farming is. In terms of shrimp-farming experience, the extensive-producing farmers were ranked the highest among the three methods of practice (Table 1). Extensive shrimp farming is the primary method of shrimp practice in this industry, which was inaugurated in 1980, while the other methods developed later (**EARSD, 2006**).

According to survey data, households were literate, with 23.33% having high school degrees, 43.33% secondary school degrees, and 33.33% with primary school degrees. In addition, the average family education level (H2) was nine years of schooling. Results revealed that, the intensive households were the most prominent because most were younger and wealthier, and their children had more educational opportunities. The extensive households had the lowest family education levels because their low incomes do not allow many adequate educational opportunities. The average household size was approximately four people, but 96% of families had non-labours with an average of two people per household being children or/and elderly; and 48.3% of families had semi-labour. Remarkably, almost all members of shrimp-farmer families are involved in farming activities, but they do not take account of wages due to the prevailing social norms in Tra Vinh. As a result, average household labour capacity (H1) was quite low at around two members per household who could work. It means that most households were burdened with one out of two dependent members. Eminently, there was no significant difference among the three methods of shrimp production.

Overall, the three indicators made human capital value lower than the medium value for all kinds of shrimp farming (Fig. 1). The intensive shrimp farmers' human capital in Tra Vinh was slightly higher than the others; this could be considered an advantage, as they are able to understand concepts of environmental responsibility. Semi-intensive and extensive were the opposite. Therefore, the higher-valued human assets would contribute to more environmental sustainability in shrimp farming.

Table 1. Statistic Values of Indicators of Human Capital.

Indicator	scale	Unit	Intensive	Semi-intensive	Extensive
Household labour capacity (H1)	Min	1 labour	0.301	0.352	0.384
	Max	5 labours			
	Average	2 labours			
Household education level (H2)	Min	5 years	0.418	0.298	0.288
	Max	13 years			
	Average	9 years			
Household experience in shrimp farming (H3)	Min	0 year	0.359	0.348	0.373
	Max	20 years			
	Average	7 years			
	No	40%			
Normalized value of human capital			0.359	0.332	0.348

Natural capital

The natural capital of shrimp farmers comprises four indicators: quality of water resource (N1), distance to water resource (N2), reservation pond (N3), and farm size per capita (N4). The study recorded 19% of shrimp farmers reporting that the water was slightly polluted, but highly polluted water was reported by 37.3% of farmers (Table 2). Water pollution has several causes, and this study revealed that aquaculture activity was cited by 63% of shrimp farmers as the main cause of water pollution. In recent years, scientists and authorities have been concerned about this issue because polluted water is one of the main causes of disease in shrimp. Effluents from shrimp ponds contain suspended soils, nutrients, residual chemicals, and pathogenic microorganisms. This problem is more severe in intensive rather than extensive shrimp farming. According to **Anh *et al.*** (**2010**), fertilizer and food waste discharged into surrounding surface water may reach 1 to 1.5 tons per ha in each crop for intensive shrimp farming. Due to the high cost of treating outlet water after harvesting or disposing of diseased shrimp ponds, there were some farmers discharging the polluted water directly into rivers or canals, which leads to diseases spreading to adjacent areas. The treatment cost of discharge water is between 4 to 5 million VND for 5,000m^2 pond size (**Anh *et al.*, 2010**). In turn, the farmers pay high costs for treating water in ponds or treating disease in shrimp at an average of 14% to 15% of total production costs in intensive and semi-intensive farming (**Sinh, 2005**), otherwise they may even experience crop losses and fall into debt because of water pollution which carries a variety of pathogens or diseases resulting from polluted water discharged from shrimp ponds. It is presumed that all shrimp farmers should obey the rule of having their water treated before discharging it, avoiding the vicious cycle of disease spreading, pollution and sustaining the shrimp farming. The survey revealed that the semi-intensive shrimp farmers believed the quality of river water to be at the highest value (0.694), while the intensive farmers recorded the lowest values for quality of river water. The extensive farmers were as optimistic about their water quality as the semi-intensive farmers.

Several drivers led to environmental pollution. Shrimp production is the main cause of polluted water and is itself a vicious cycle. The shrimp industry has rapidly expanded in recent years in both productivity and area covered. Moreover, the majority of shrimp farmers work at a small-scale volume-wise; the survey data recorded that 59% of shrimp-farmer households own a farm (N4) less than 0.5ha in size, while households owning from 0.5 to 2ha of farmland accounted for 13%. This circumstance makes it difficult to control solid waste and wastewater in shrimp farming. It is beyond the local authority’s ability to control all contravention in the term environment. Although there were several laws related to environmental protection promulgated in order to develop the shrimp industry into an environmentally sustainable business, the implication of the laws is weak. Under the **Decision 784/QD-UBND** of Tra Vinh province dated 27 April 2018, ‘Developing shrimp farming industry to 2025’ refers to improving environmental management systems with intensive and super-intensive shrimp production. The law mandates that a household owning a farm from 0.5 to 10ha in size has to sign an environmental declaration, and households with over 10 ha of farm size must report environmental effects periodically. In addition, the **Circular No. 27/2015/TT-BTNMT** dated 29 May 2015 requires all shrimp farmers to properly treat outlet water, and sediment and sludge must have reservation ponds equivalent to 10% to 15% of the pond size. Those legal actions were put forth in the hope that they would be steps forward in contributing to sustainable shrimp farming. However, there is a significant drawback in treating waste from shrimp production. In terms of technology, there are some feasible measures to eliminate effluents in ponds; circulation of water farming using beneficial algae and probiotics to deal with organic wastes. But the cost burden for those measures becomes a significant obstacle for small-scale farmers, even if they act sustainably with respect to the environment and ecology. Another problem is that shrimp farmers are often not properly educated about the disseminated diseases and environmental risks. They are mainly concerned about their shrimp ponds and do not pay adequate attention to the water resources in rivers or canals that are more and more susceptible to untreated discharge water. In fact, when their neighbors were discharging polluted water into rivers or canals, these farmers were inclined to do the same. It seems that there is no benefit conflict in using the common pool.

Table 2. Statistic Values of Indicators of Natural Capital.

Indicator	Scale	Percent	Intensive	Semi-intensive	Extensive
Quality of river water resource (N1)	Definitely unpolluted	0%	0.537	0.694	0.636
	Low pollution	19%			
	Generally polluted	40.33%			
	Very polluted	37.33%			
	Very highly polluted	3.33%			
Distance to water resource (N2)	Under 30m	78%	0.867	0.910	0.912
	From 30m to 50m	19%			
	Over 50m	3%			
Reservation pond (N3)	Yes	60%	0.651	0.823	0.000
	No	40%			
Farm size (N4)	<= 0.5 ha	59%	0.015	0.149	0.315
	from 0.51ha to 2.0ha	13%			
	> 2.0 ha	28%			
Normalized value of natural capital			0.518	0.644	0.466

As mentioned previously, shrimp farming is quite environmentally sensitive, especially in terms of water resources. Those farmers who do not reserve quality water for water exchange during the shrimp crops would be at risk of contracting disease from a common pool. Hence, the reservation pond (N3) plays a vital role in shrimp farming. Besides its function of storing water, it is also used to treat discharge water from shrimp ponds after harvesting crops. The data showed that 60% of shrimp farmers had reservation ponds; those without reservation ponds accounted for 40% of the total (**Table 2**). Specifically, those are numbers for intensive shrimp farming with 65% and semi-intensive shrimp farming with 82.3% who have reservation ponds. Extensive shrimp farming does not need reservation ponds due to its particular characteristic. A majority of intensive and semi-intensive farmers who have no reservation pond would either accept the risk of polluted water when water is exchanged during crop or they might decide to use groundwater. And they have no options for treating discharge water, which is recognised as the main driver of polluted water in rivers and canals around shrimp farming areas. Although extensive shrimp farmers use less food and fewer chemicals compared to the other categories, extensive farming is still more or less harmful to the environment because of the dramatic loss of mangrove forest area in recent years. The extensive shrimp farming is located mainly in the Duyen Hai district where the mangrove forest area has declined from 12,797ha in 2001 (**Thu *et al.*, 2007**) to 4,083ha in 2010, with the annual rate of reduction of mangrove forest being 6.8% (**Hiep *et al.*, 2016**). Moreover, the adverse effects from the climate change context caused a shortage of brackish water in the dry season and higher salinity in water in the shrimp-farming areas. Hence, the reservation pond is required for all methods of practice.

Almost all shrimp farmers' ponds were relatively close to a water resource (N2) with 78% of them within 30 meters of a water resource, the average distance was about 28 meters (Table 2,4). Because shrimp farms are developing along rivers or canals, they are conveniently located near inlet and outlet water. According to the Department of Natural Resources and Environment of Tra Vinh province, there are 110 canals at level 1 with a total length of 467 km; 690 canals at level 2 with a total length of 2,110 km; 8,800 canals at level 3 with the length of 6,620 km. In general, shrimp farmers in Tra Vinh province have good access to water resources owing to the dense networks of rivers and canals. This indicator was favourable to all shrimp farming methods which are shown in **Table 2** with relatively high values.

Overall, the current status of the natural capital of shrimp farmers in Tra Vinh was just at a medium level due to the four indicators mentioned above (Fig. 1), in which the lowest value goes to extensive farming and the highest value to semi-intensive farming (**Table 2**).

Physical capital

In this study, two indicators were chosen: the quality of the house (P1) and the household assets (P2) as physical capital. Referring to the quality of the house, 80% to

90% of all shrimp farmers were living in cement-and-brick houses. General data recorded 89% of shrimp-farming families living in the level of 4 houses made from cement and brick with corrugated iron roofs (**Table 3**) in general. This kind of house can last up to 30 years (**Joint circular No. 07- LB/TT** dated 30 September 1991). Just 11% of these families lived in a cottage-style house made from bamboo or mangrove wood with nipa palm leaf. Under caution from the Vietnam Disaster Management Authority, the level of 4 houses could withstand winds up to grade 7 (on the Beaufort scale) in case of tropical low pressure and could be damaged in a typhoon because the Mekong Delta is located in the lower frequency typhoon area in general, and Tra Vinh province was affected only slightly by two typhoons (Category No.5- Linda storm in 1997 and Durian in 2006). However, shrimp-farming families could be at risk in extreme weather contexts.

One hundred percent of shrimp-farming households have three essential assets: televisions, cellphones, and motorbikes. Most of them also have a refrigerator for storing fresh foods (**Table 3**). But, no one has a boat because almost all the families have access to roads, which is a more convenient and quicker way to travel than using small boats. The list of household furniture was chosen based on the living conditions of the farmers. Those items were essential assets that would help them lead more comfortable lives. As a result of the survey, 32.7% of families had five out of ten assets on the list. Three percent of families had a maximum of eight assets and 11% of families had a minimum of three assets. Overall, the value of this indicator (P2) was lower than the medium level; from 0.365 to 0.439 for semi-intensive, extensive, and intensive respectively.

Overall, two indicators mentioned previously contributed to the normalized value of physical capital higher than the average level, ranked in order by semi-intensive, extensive, and intensive households (Fig.1).

Social capital

Social capital refers to all benefits from relationships, community networks, and access to necessary information for livelihood strategy (**DFID, 1999**). For shrimp farmers, social capital was measured through neighbor relationship (S1), the degree of frequency of accessing information (S2), distance to the nearest relatives (S3), and taking part in community activities (S4).

The normalized value of the neighbor relationship (S1) was over 0.6 for all shrimp-farming methods. The shrimp farmers almost reported that they have a very good and good relationship with their neighbors with 37.3% and 35.6%, respectively. The remainder had an acceptable relationship with each other, and the lower medium accounted for a small percentage (Table 4). With good relationships, the farmers would benefit from neighbors' willingness to help, sharing their experiences or benefitting from their support in some cases. Although you would not get any material support, you would feel good that someone else advocates or stands behind you. Based on the traditional culture of Vietnam, the relationship between neighbors is always friendly. In fact, approximately all of the shrimp farmers are ready to help and share experiences with their neighbors. The relationship with relatives (S3) also plays an important role in shrimp farming. Because relatives (parents, siblings, cousins) could lend a hand in difficult situations in terms of finances and encouragement. Therefore, living close to relatives is an advantage. And the survey revealed that shrimp families were living within a radius of 10km was 36%. The average distance to their nearest relatives was 28km, and those living further than the average distance only accounted for 21% of the total. Hence, the normalized value of distance to the nearest relatives was pretty high, from 0.914 for the all shrimp farming households (**Table 4**).

Table 3. Statistic values of indicators of physical capital.

Indicator	Scale	Percent	Intensive	Semi-intensive	Extensive
Quality of house (P1)	cottage	11%	0.903	0.839	0.884
	cement and brick (level 4)	89%			
Household assets (P2)	television	100%	0.439	0.365	0.409
	entertainment media	42.33%			
	cell phone	100%			
	motorbike	100%			
	small boat	0%			
	car	0.33%			
	air conditioner	15.67%			
	washing machine	49%			
	refrigerator	95.67%			
	internet access	6.67%			
Normalized value of physical capital			0.671	0.602	0.647

Getting news on a daily basis (S2) also plays a vital role in shrimp farming such as keeping up with weather news, season crop incentives, fluctuation of shrimp prices, and so on. Without that information, it is easy to make bad decisions. The study recorded that almost all shrimp farmers had access to information through television. Twenty-three percent of households were updated with news every day, and more than 30% got the news regularly; farmers who rarely or never got updated news was a tiny percentage (Table 4). The scheme of shrimp crop was informed by local authorities in order to assure that every farmer begins a new crop at the same time. This action helps control disease-spread because it is also based on the climate conditions suitable for shrimp farming. The intensive and semi-intensive farmers are especially concerned with this issue strictly because of the high density of shrimp stocking and high sensitivity to weather changes. In contrast, the extensive farmer paid less attention to obtaining that information because of its particular characteristics, such as low density and year-round stocking. Therefore, the normalized value of this indicator was the highest for intensive shrimp farming and the lowest for the extensive farming (Table 4). Additionally, a majority of shrimp farmers did not take part in community activities (92%) including festivals and sport clubs. Hence, the normalized value of taking part in community activities was very low for all the farming methods. Despite those activities prevailing in each local area, only children and people who do not work take part in them. Shrimp farmers are busy with their shrimp ponds, although they have occasional meetings and they share experiences, building a close relationship with the community. The farmers need a practical activity such as a shrimp farmer club where they can meet weekly or monthly to discuss technical problems related to shrimp farming. Nearly 60% of surveyed shrimp farmers agreed to establish a shrimp farmer club.

With the advantage of living close to relatives, having a good relationship with neighbors and frequently access information but rarely attend local community activities: as a result, the value of social capital was highest for intensive farming and lowest for extensive farming (Fig. 1).

Table 4. Statistic values of indicators of social capital.

Indicator	Scale	Percent	Intensive	Semi-intensive	Extensive
Neighbor relationship (S1)	Very good	37.33%	0.721	0.608	0.643
	Good	35.67%			
	Medium	22.67%			
	Lower medium	4.33%			
	Very bad	0%			
Degree of frequency of access to information (S2)	Every day	23.33%	0.756	0.577	0.238
	Regularly	30.67%			
	Sometime	31.67%			
	Rarely	9.33%			
	Never	5%			
Distance to nearest relatives (S3)	Within 10km	36%	0.920	0.914	0.945
	Within 20km	57%			
	Within 30km	79%			
	Over 30km	21%			
Taking part in community activity (S4)	Yes	8%	0.041	0.145	0.233
	No	92%			
Normalized value of social capital			0.610	0.561	0.515

Financial capital

Financial capital encompasses all kinds of tangible property which can be liquidated into cash. Those financial resources are allocated for investment with an aim to achieve livelihood objectives **(DFID, 1999).** For shrimp farming, financial resources play a very important role that determines whether a farmer can continue farming in case of crop losses or investments needed to adapt to severe climate change conditions.

In this study, financial capital refers to having access to bank loans (F1), credit from relatives (F2), having a savings account (F3), and annual income from shrimp farming per capita (F4). The recorded data revealed that 72% of shrimp farmers could not access bank loans (Table 5). Most of the households that had an area of less than 2ha (Table 2) were those of intensive and semi-intensive shrimp farmers who needed more money to invest in facilities and equipment for cultivation. However, they found it difficult to access credit from the banks due to the low value of their farmland. As a result of the normalized value, the bank’s offerings of credit were dramatically low for extensive farming.

In terms of credit for shrimp farming, besides bank credit, the study recorded that 10% of households were borrowing money from their relatives. An advantage of this approach is that it is based on prestige or trust rather than the value of mortgage property. However, intensive shrimp farming did not take full advantage of this credit, only 18.6% and 16% of the extensive and semi-intensive farmers, respectively, could access credit from relatives. By contrast, more than 70% of intensive and semi-intensive households had a savings account, while approximately 50% of the extensive households had one. Holding a savings account would be considered a safety net in adverse financial situations whether these scenarios involve reinvesting in shrimp farming, an ill family member, or school fees for children. Although the annual income from shrimp farming per capita was under 25 million VND and accounted for 51.3% of shrimp farmers, a large proportion of shrimp-farmer households saved large amounts of money for financially trying situations. Consequently, the normalized value of the savings account indicator was relatively high for the three shrimp farming methods.

The survey reported that the annual income of individuals was approximately 35 million VND. There was only 15.3% of households with an annual income per capita of over 50 million VND (Table 5). The annual income was calculated from shrimp-farming earnings after deducting all costs for the shrimp crops and not yet considering the household’s expenditures. The study used income per capita as an effective indicator to measure the financial capital because the productivity from shrimp farming varies between intensive, semi-intensive, and extensive farming. Although the shrimp productivity per hectare of extensive farming was the lowest, its farm size was the largest among the three shrimp farming methods. The average farm size was 5.7 ha for extensive farming, 2.6ha for semi-intensive farming, and just 0.3ha for intensive farming. Thus, the average annual income per capita for extensive farming, semi-intensive farming, and intensive farming was 41.7 million, 56.7 million, and 26 million VND, respectively. The normalized value of this indicator was the lowest for intensive farming, which was approximately equal to half of the two other values.

In general, the normalized value of the financial capital of shrimp farmers in Tra Vinh province was very low (**Table 5**). They found it difficult to secure credit from both banks and relatives. Intensive farming is considered a high-profit farming model but with a high risk of spreading disease. Hence, its annual income per capita was lower than the other forms.

Table 5. Statistic values of indicators of financial capital.

Indicator	Scale	Percent	Intensive	Semi-intensive	Extensive
Access to bank loans (F1)	Access to bank loan	28%	0.292	0.339	0.140
	No access	72%			
Borrowing money from relatives (F2)	Yes	10%	0.097	0.161	0.186
	No	90%			
Having a savings account (F3)	Yes	72%	0.749	0.726	0.488
	No	28%			
Annual income from shrimp farming per capita (F4)	under 25 million VND	51.30%	0.108	0.265	0.188
	from 25 to 50 million VND	33.40%			
	from 50 to 200 million VND	15.30%			
Normalized value of financial capital			0.312	0.373	0.268

Based on the aforementioned analytical data Fig. (1) shows that, shrimp farmers' livelihood assets were lower than the mean value in terms of financial and human capitals. The three remaining capitals were just higher than the mean value but under a good point (0.7). The overall values of livelihood assets were ranked in order from the highest to the lowest for semi-intensive, intensive, and extensive farmers, respectively. Semi-intensive farmers had more financial and natural capital than the farmers of other systems. In contrast, the intensive farmers recorded the highest values for social and physical capital. Moreover, the extensive farmers' livelihood assets were the lowest of them all, except for their physical capital.

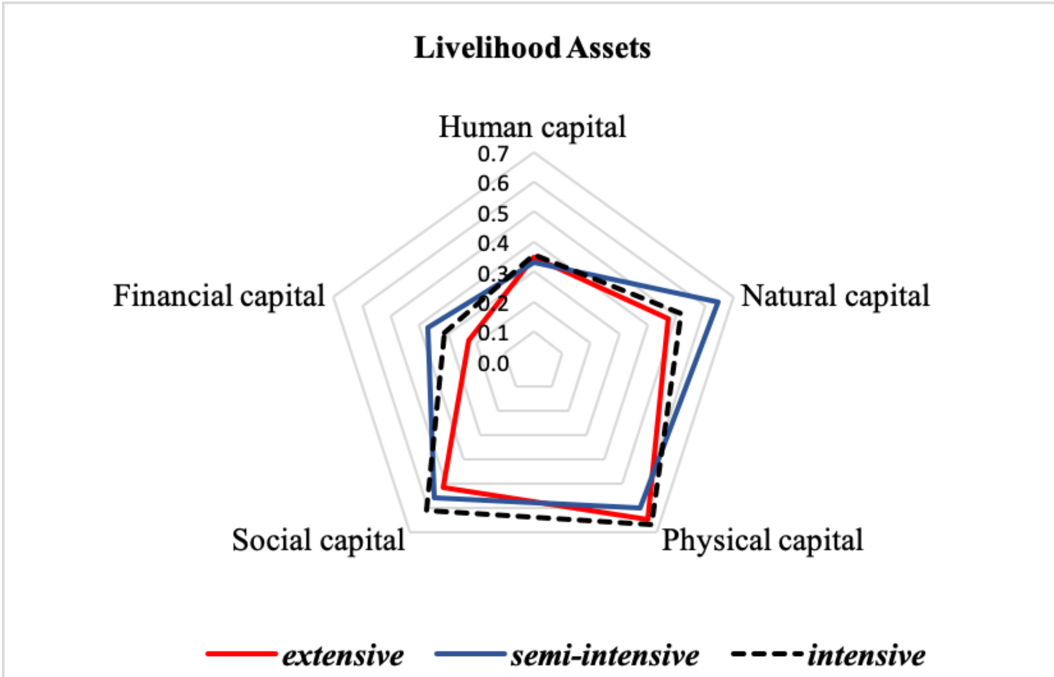

Fig. 1. Current Status of Five Livelihood Assets of Shrimp Farmers Classified by Shrimp Farming Method in Tra Vinh Province**.**

The effect of livelihood assets on the environmental sustainability of shrimp farming

In this study, the dependent variable is the environmental sustainability of shrimp farming (*Env_sus*) measured by a list of 19 criteria (Table 6). Those chosen criteria used in the current study followed the methods of **Roennback** (**2002**), **Manoj *et al.*** (**2009**), **Valenti *et al*.** (**2011**), **Chowdhury *et al*.** (**2015**). The Vietnamese environmental laws were also taken into account as well as other expert opinions.

To preserve the shrimp-farming environment, the farmers have to control both input and output water under the technical and environmental laws. To satisfy the technical aspect, proper input water treatment is required to meet the quality standard for shrimp farming. However, using chemical substances to treat water and using medicine remedies to cure shrimp diseases have to be compliant with regulations. All illegal chemicals or abusing legal chemicals would do more harm than good to the environment surrounding shrimp farms. The permitted chemical to treat input water is usually chlorine, BKC (benzalkonium chloride), or saponin to guarantee there are no wild aquatic species before shrimp-larvae cultivating. The data reported 86% of farmers treated the input water, but 18% used pesticides to kill wild crustacean due to the low costs involved or lack of knowledge of the harm it does to the environment, or both. One hundred percent of shrimp farms used chemicals to treat water in ponds under strict official regulations, and there were almost no farmers using substances to stimulate shrimp growth. Sixty percent of farmers were recorded as having treated discharge water. Discharge water contains pollutants, eutrophication, and residual chemicals that would be harmful to natural aquatic species, and they would pose a risk of spreading disease to adjacent farms. Hence, the treatment outlet is not only required by law, but it is also farmers' responsibility to common natural resource. In addition, to avoid accretion in rivers or canals due to solid sediment from shrimp ponds, shrimp farms must have enough land for pumping sludge from the ponds. The data showed that 80% of farms met this requirement.

Table 6. The List of Criteria for Environmental Sustainability of Shrimp Farming in Tra Vinh province.

#	**Criteria**	**Response (%), N=300**	
		Yes	No
1	Treatment of input water	86%	14%
2	Treatment of wastewater (effluent water)	60%	40%
3	No use of groundwater in shrimp farming	36%	64%
4	Developing the shrimp farms in low salinity to minimize the risk of salinisation of adjacent soil and water	100%	0%
5	Having an environmental certification in shrimp farming	0%	100%
6	Building sluice gates and dikes to protect saline water intrusion or flood	83%	17%
7	Benefits by having government-managed water flow	86%	14%
8	Access to electricity power	100%	0%
9	Access to path or street directly for transport.	100%	0%
10	Taking part in shrimp production training courses	60%	40%
11	Using culture system that utilizes natural or stimulated production in ponds or incoming water	35%	65%
12	Using formulated food from prestigious suppliers	100%	0%
13	Having land used for pumping sludge from the ponds	80%	20%
14	Does not use pesticides that kills wild crustaceans	82%	18%
15	Using chemicals to treat water in ponds under strict official regulations (only use permitted chemicals)	100%	0%
16	Use medicines (antibiotics) to remedy shrimp diseases under strict official regulations	100%	0%
17	No substances used to stimulate shrimp growth	99%	1%
18	Use seed from the local prestigious hatchery suppliers	67%	33%
19	There are always available buyers	100%	0%

Besides the technical requirement for building sluice gates, dikes must be reinforced to protect against seepage problems, floods, or sea-level rise in the context of climate change. Moreover, shrimp farms are located in areas planned by local authorities, which aims to minimize the risk of salinisation of adjacent land and water (**Roennback, 2002; Decision 109/QD-UBND dated 18 January 2018**). Brackish shrimp farming requires a salinity range of 15-25ppt (**MOFI, 2006; Anh *et al.*, 2010**), which is not suitable for growing rice, fruit trees, or for vegetable growing. Therefore, all shrimp farms in Tra Vinh province are located in the planned areas run by local authorities. In the specialized locations, shrimp farms could receive the benefits of water management in the form of maintaining the right water levels of rivers or canals for each season. As a result, 86% of farmers were satisfied with this service. In addition, the planned farm areas have easy access to electricity and have the necessary power for lighting and aerator systems. Long ago, before farmers had electricity, they used diesel engines to operate the aerator system and the lights. The diesel engine is not only highly charged, but also pollutes the environment with its fumes and leaking oils. Today, the government has brought a power approach to all the planned shrimp farms. The government must also facilitate transportation of materials needed for farming or harvesting by building the convenient roads or paths to those areas.

In order to heighten farmers' sense of environmental responsibility, annual training courses are run by the local authorities (Table 7). For instance, the Preservation of Natural Sources course improved farmers' awareness of environmental protections. VietGAP (Vietnamese Good Aquaculture Practice) courses are especially good for not only helping shrimp farmers harvest the highest-quality shrimp but also for teaching farmers how to be environmentally conscious. Therefore, attending those courses would increase the environmental sustainability of shrimp farming. Although so far there is no farmer getting an environmental certificate, shrimp output can always be sold easily due to an abundance of available buyers. The study recorded just 60 percent of shrimp farmers concerned and took part in those courses, although the report of the Aquaculture Department of Tra Vinh province stated that they have organised several training courses for shrimp farmers all over the province about environmentally sustainable shrimp farming. Some reasons the farmers gave for not being interested in those training courses were that it was difficult to apply what they learned, being beyond their abilities, or they had no time to participate.

Using groundwater in shrimp farming is considered environmentally unsustainable in the long term. The study reported 64% of shrimp households were pumping groundwater to supplement water during the harvest. Uses such as balancing pH degree, compensating for evaporated water, and exchange water for shrimp ponds were recorded. This extraction was involved in intensive (90%) and semi-intensive (27%) shrimp farming but not in extensive shrimp farming.

Table 7. Training Courses in the Last Five Years.

Course	Unit	2015	2016	2017	2018	2019
Law applied in aquaculture activity	Class	40	39	51	94	87
	Participants	1,069	1,080	2,280	3,053	3,425
Good Aquaculture Practice of Vietnam (VietGAP)	Class	99	40	52	21	0
	Participants	2,611	953	1,350	525	0
Preservation natural aquatic resource	Class	39	30	53	35	Brochure
	Participants	1,030	870	880	1,076	5,500
Scientific meeting	Times	4	4	6	0	0
	Participants	230	182	215	0	0
Local broadcasting on television	Times	4	4	16	9	12

Source: Ministry of Agriculture and Rural Development- Aquaculture Department of Tra Vinh province. Annual Final Report of Aquaculture production of Tra Vinh province.

Groundwater exploitation is cited as the main cause of subsidence in the Mekong Delta. Its average rate of subsidence has been about 1.1 cm annually over the past 25 years; this trend is likely to increase in the near future (**Minderhoud *et al*., 2017**). Because the surface water is increasingly polluted and salinated, groundwater has become an optimal choice for meeting the urgent demand (**Wagner *et al*., 2012**). Hence, groundwater level and storage capacity are proposed to decrease gradually over the years, and salinisation of groundwater would exacerbate and expand (**Vuong, 2014**). Nowadays, surface water shortages and seawater intrusion prevails in the Mekong Delta, which accelerated groundwater exploitation in agriculture activities and aquaculture production. Furthermore, shrimp farmers used groundwater because of the polluted water resources and to avoid the risk of spreading disease.

The consequences of groundwater extraction are a grave concern of scientists and authorities in the context of climate change (Fig. 2). The study revealed that, nearly 100% of shrimp farmers did not realize excessive groundwater extraction was the main factor leading to subsidence and seawater intrusion in the Mekong Delta in general. In fact, polluted water resources led to increased conflict among shrimp farmers. They realised that there would be risks when adding water to growing shrimp ponds if their neighbors are discharging water directly into rivers or canals without treatment. To protect themselves, groundwater was used as a short-term solution. Groundwater use for shrimp and fish farming is banned by Tra Vinh province’s authority under **Decision No. 19/2015/QD-UBND** dated 10 August 2015. The enforcement of the law, however, is erratic because farmers claim to use groundwater for domestic purposes, or they stop pumping temporarily to avoid the scrutiny of authorities.

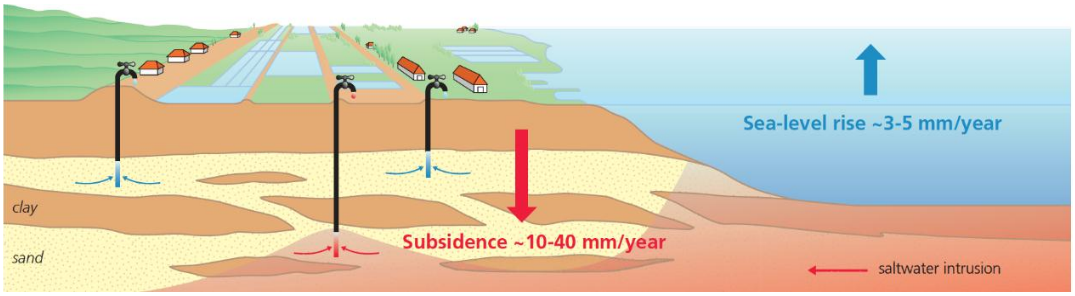

Fig. 2. Illustration of Groundwater Extraction.

Source: Dr. E. Stouthamer, Prof. Dr. P. Hoekstra, Dr. G. Oude Essink, PhD, Minderhoud, MSc. and Dr. H. Otter. Utrecht University. Report from Rise and Fall research program.

The environmental sustainability of shrimp farming is also related to the quality of the food which not only affects the shrimps' health but also reduces the food conversion rate. Food waste is the main cause of a high concentration of nutrients and organic matter in the shrimp ponds. They, in turn, create harmful algal blooms, sulfide compounds, and oxygen depletion. The survey recorded all farmers using formulated food from the brand-name companies. However, to decrease the accumulation of sediments from the food waste, utilising natural or stimulated food in ponds is considered a positive attribute of shrimp farming. Today, bio-floc technology is very popular in shrimp farming in some countries such as Thailand, China, and India. In Vietnam, this system has been tried in recent years but has not been popular. The study reported 35% of shrimp farms—intensive, semi-intensive farming—stimulated natural food in the first phase of stocking, and extensive farming utilized natural food during this process as the main food resource.

The best approach is using seed from prestigious local hatcheries that have a certificate of being clear of post-larvae disease. In terms of environmental sustainability, this action helps prevent disease from spreading. According to provincial quarantine regulations, all imported seeds from outside provinces have to present a certificate showing non-diseased seeds or wait for the results of testing by the local quarantine agents. However, there are several cases that are not declared at the quarantine agents, which contributes to disease outbreaks. Therefore, using prestigious local seeds would enhance the environmental sustainability of shrimp farming. The data showed that 67% of shrimp farmers bought post-larvae from the local hatcheries.

Similarly, the final criterion is considered as a factor affecting the environmental sustainability. Because available buyers would deal with all shrimp crops that are mature to harvest or be at risk cases needing to harvest early, otherwise shrimp may die causing environmental problems. The farmers responded that shrimp buyers are always available to collect all shrimp at any time. Overall, the environmental sustainability of shrimp farming was measured by several criteria to guarantee a reliable calculation of the normalized value. As a result, the value of the *env_sus* was relatively higher than the mean point. The semi-intensive practice had the highest environmental sustainability, while the intensive was second, and the extensive farming approach had the lowest value of environmental sustainability (Table 8).

.Table 8. Statistic Values of the Dependent Variable**.**

Env_sus (Environmental sustainability of shrimp farming)	**Scale**	**Value**	**Intensive**	**Semi-intensive**	**Extensive**
	Min Max	0.632 0.947	0.779	0.851	0.652

The Stata MP version 14 was used to estimate the regressions (Appendix B). And the results are presented in the Table (9).

Table 9. The result of estimating five Capitals Affected the Environmental Sustainability of Shrimp Farming.

VARIABLES	**env_sus**	**VARIABLES**	**env_sus**
Human_capital	0.0913 (0.0435) **	H1 (Household labour capacity)	0.00944 (0.0241)
		H2 (Household education level)	-0.0155 (0.0282)
		H3 (Households' experience in shrimp farming)	0.0374 (0.0206) *
Natural_capital	0.266 (0.0278)***	N1 (The quality of water resource)	0.00268(0.0130)NS
		N2 (Distance to water resource)	0.0265 (0.0447)
		N3 (Reservation pond)	0.0954 (0.00760)***
		N4 (Farm size)	-0.115 (0.0378)***
Physical_capital	0.0178 (0.0207)	P1 (Quality of house)	0.00566 (0.0106)NS
		P2 (Household assets)	-0.00955 (0.0156)NS
Social_capital	0.0312 (0.0314)	S1 (Neighbour relationship)	-0.0170 (0.0116)N
		S2 (Degree of frequency of accessing information)	0.0153 (0.0151)NS
		S3 (Distance to nearest relatives)	0.0206 (0.0318)NS
		S4 (Taking part in community activities)	-0.0162 (0.0122)NS
Financial_capital	0.127 (0.0289)***	F1 (Access to bank loans)	0.0310 (0.00855)***
		F2 (Borrowing money from relatives)	0.0113 (0.0123)NS
		F3 (Having a savings account)	-0.00294 (0.00877)NS
		F4 (annual income from shrimp farming per capita)	0.0764 (0.0273)***
Constant	0.532 (0.0328)***	Constant	0.658 (0.0584)***
Observations	300	Observations	300
R-squared	0.2959	R-squared	0.4982

Standard errors in parentheses
**** p<0.01, ** p<0.05, * p<0.1, NS: p≥0.1*

The study carried out two regressions. The first regression was to find the relationship of five livelihood capitals to the environmental sustainability of shrimp farming (*env_sus*). The second regression consisted of seventeen explanatory variables which derive from the five capitals, with the *env_sus* as the dependent variable.

Table (9) shows that three out of five livelihood capitals have positive coefficients and statistical significance. The coefficient of multiple determinants (R^2) for *env_sus* is relatively low (0.296) which means that the *env_sus* was explained approximately 30% by the five livelihood capitals, while the second regression the *env_sus* was explained approximately 50% by 17 indicators. However, according to **Gujarati** (**1995, p. 211**), researchers should be more concerned about the logic or relevance of the explanatory variables to the dependent variables and whether they are statistically significant.

The human capital variable has a positive relationship with the *env_sus* at the significance of p-value < 0.01 in the first regression. Based on **DFID (1999)** and expert opinions, in this study three indicators were used to calculate its value (Appendix A). In the second regression, the households' experience in shrimp farming (H3) variable was the only factor influencing the environmental sustainability of shrimp farming. It means that farmers who have more years of experience in shrimp farming act with more environmental responsibility. This is because over time, those farmers have recognized adverse changes in the environment.

The *env_sus* is dependent mainly on the natural capital with the highest coefficient value at a significance level of 1%. This implies that the *env_sus* would increase if the value of natural capital increases with the ceteris paribus assumption. In the second regression, the farm-size variable (N4) has a negative relationship with the *env_sus*. It indicates that households with larger farms tend to be responsible for more polluted water and face difficulties in farm management and disease control. Because wastewater from shrimp ponds discharges into the environment at an average of 28,330 to 37,930m^3/ha/crop (**Anh *et al*., 2010**) for intensive and semi-intensive farming, and 123 tons/ha/crop of sediment for a density of 25 post-larvae/m^2 (**Manh and Nga, 2014**). By contrast, the reservation pond (N3) variable has a significantly positive effect on the *env_sus*. To meet desirable farming standards continuously all year, even in the dry season when there is a scarcity of freshwater and more saltwater intrusion, the reservation pond is an effective way to confront those problems. The remaining independent variables such as quality of water resource (N1) and distance to water resource (N2) did not have a statistically significant impact on the *env_sus*.

The financial capital variable influences the *env_sus* somewhat positively, at a highly significant level of 1%. Two of four indicators have statistical significance at 1% and 5%. The remaining independent variables are not statistically significant because credit from relatives could not be an official and stable means of financing shirmp farming in the long term. Similarly, a savings account in households is usually used for family-related emergencies or school fees for children rather than reinvestment in shrimp farming. By contrast, annual income per capita (F4) and access to bank loans (F1) positively impact on the environmental sustainability of shrimp farming. It means that the higher the annual income per capita, the more environmentally sustainable shrimp farming is. This is because the successful people in shrimp farming have tended to be more concerned about environmental issues relating to their prospects. Furthermore, in the climate change context, the shrimp industry is facing more and more difficulties. Sufficient financial resources play an important role in investing in facilities and equipment to adapt to severe climate patterns: for example, installing more aeration systems in shrimp ponds to guarantee sufficient oxygen for shrimp, covering the plastic sheet at bottom of the pond to avoid being contaminated from soil; covering net over the pond to limit evaporation and infectious disease agents from the sky (birds eating shrimp). Besides annual income, having access to bank credit also increases the environmental sustainability of shrimp farming. Because the bank credit helps farmers overcome the bad financial situations like lost crop, or invest in the eco-environmental farming such as following the VietGAP standard.

CONCLUSION

The study showed that shrimp farmers in Tra Vinh province had moderate livelihood assets' values. The financial capital was a big problem for shrimp households. A majority of farmers found it difficult to access financial credits for investing in farming due to the small scale of farming and the low value of pledged land. In term of natural capital, they exposed some risk actions. Prevailing using groundwater in shrimp farming and have no reservation pond could not meet the conditions of sustainable shrimp farming.

The result of the first regression found that three livelihood assets had a positive effect on the environmental sustainability of shrimp farming, while physical capital and social capital had no statistical significance. The second regression also stated that to avoid harm to the environment, using reservation ponds for treating water and storing water for shrimp farming are necessary for sustainable farming without compromising groundwater. Shrimp farmers should drop their short-term vision for a long-term outlook. Protection of the environment in shrimp farming is likely to ensure their future survival.

The limitations of this study are that some indicators of the forms of livelihood capital and a few criteria related to environmental sustainability of shrimp farming might be subjective and only pertain for shrimp farming in Tra Vinh province. In addition, in this study, the sustainability of shrimp farming only encompasses the environmental aspect. While the overall picture of sustainability comprises three main pillars: economic, social, and environmental sustainability. However, the findings of this study contribute to the relationship between indicators of the livelihood assets and the environmental sustainability of shrimp farming in terms of quantitative method. The study should also inspire further research in general on the sustainability of shrimp farming and more specifically for each shrimp-farming production method.

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