Sustainability of the rice-shrimp farming system in Mekong Delta, Vietnam: a climate adaptive model

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Abstract

Purpose – Agricultural systems in Mekong Delta have transformed to cope with climate change. Various researches pointed out that integrated agriculture-aquaculture (IAA) farming systems (i.e., rice-shrimp, rice-fish. . .) emerged as potential climate adaptive practices. However, limited studies are attempting to assess the sustainability of these agricultural practices. Therefore, it is essential to assess whether or not these systems will be sustainable in the context of climate change and what can be done to make it sustainable. The present study conducted the sustainability assessment of the rice-shrimp system to identify potential areas for improvement as well as policy implication to increase resilience and adaptation of coastal IAA system which could contribute to the understanding of other coastal agricultural deltas around the globe.

Design/methodology/approach – This study used a quantitative approach including the assessment protocol of van Asselt *et al.* (2014), the assessment framework of Vanloon *et al.* (2005), and the MCA methodology to flexibly and holistically assess the sustainability level of agricultural systems.

Findings – Results concluded that rice-shrimp systems have the potential to improve livelihood, food security, and adaptation of coastal farmers. Major improvements should be considered for productivity, efficiency, and equity themes, while minor improvements can be made for stability, durability, and compatibility themes.

Originality/value – This research could be used as a guideline for sustainability assessment in a context-specific case study of IAA, which showed a potential for the application of other climate-smart IAAs in similar contexts around the globe.

Keywords Sustainability assessment, Multiple criteria analysis, Climate change, Integrated farming system

Paper type Research paper

1. Introduction

Back in the early 1990s, in Mekong Delta, rice culture dominated farming activities in terms of meeting subsistence needs, and other livelihood alternatives including aquaculture, fruit production, and livestock were trivial (Nhan *et al.*, 2007). Since 1999, the Vietnamese government has promoted diversification in agriculture by increasing the contribution of aquaculture, while shrinking down the proportion of rice in the total agriculture production output (Luu, 2002).

From 2010 to 2017, aquaculture in Ben Tre province grew faster than both fisheries and rice paddy as a whole (GSO, 2017). In the same period, the growth rate of aquaculture production was approximately 54 percent, while that of fisheries was approximately 43 percent. The production of rice paddy decreased by 34 percent, giving room to aquaculture by following the aim of the province. Integrated agriculture-aquaculture systems (IAA) were

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widespread and contributed to the diversification theme of local development (Nhan *et al.*, 2007; Nguyen *et al.*, 2016). IAA farming came in various combinations between fish, shrimp or prawn, livestock, and rice cultivation on the same field. Among them, rice-fish and rice-shrimp are being promoted in research areas by local authority as a sustainable way to improve the livelihood of local farmers. Unfortunately, there was obvious evidence that signaled an unsustainable development of farming in the coastal area of Ben Tre. One of the reasons was the severe saline intrusion into groundwater and surface water in the Mekong Delta due to the increasing sea levels, which made Ben Tre one of the most vulnerable coastal areas (World Bank, 2010; Renaud *et al.*, 2015; GSO, 2016). The impact of increased sea levels also included soil loss, inundation, drought, erosion, and desertification (IMHEN, 2010), which could hamper or threaten the development of coastal agro-ecosystems. Indeed, GSO (2017) reported an earlier flood in the Mekong River Delta impacted the cultivation progress, areas, and crop productivity. Unsurprisingly, in the report on the integration of land use plan for 2018, People Committee of Thanh Phu District (2018) proclaimed that the entire groundwater in Thanh Phu District was salinized with excessive mineral levels prescribed for a human. Besides, MARD (2016) concluded that changes in upstream damn operations from countries such as China, Thailand, and Cambodia resulted in unqualified river water with low alluvium or sediment loads. For the mentioned reasons, the role of IAA became more critical to the adaptation of climate change in coastal areas. However, climate change is challenging IAA farming with more severe drought, flood fluctuations, increased environmental temperatures, and unusual weather; as a result, along with low water level, the increase in water temperature is jeopardizing the sustainability of aquaculture (Leigh *et al.*, 2017; Quach *et al.*, 2017; Poelma, 2018). Moreover, IAA farming requires knowledge and proper techniques to produce more efficiently and effectively, especially for brackish IAAs, which farmers lacked (Loc *et al.*, 2017; Poelma, 2018). Furthermore, other environmental stresses, such as cross-infection from intensive aquaculture, could also pose threats to IAA farming. Overall, the sustainable growth of IAA in the context of unpredictable climate changes remained a puzzle to the authority to accomplish resilient agro-ecosystems. Very few studies successfully addressed the problem.

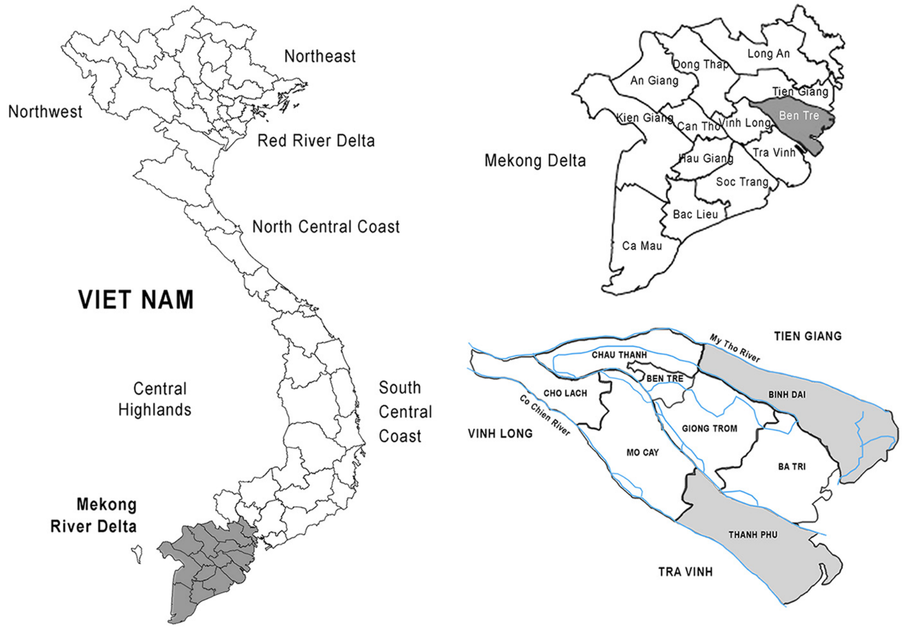
This study aimed at investigating the sustainability of rice-shrimp, the most popular IAA farming system in the study area, to determine how farmers can adapt to climate change, and to recommend possible adaptations, if any, for current farming practices. We conducted both top-down and bottom-up approaches to shed light on the current IAA farming system to identify potential areas for improvement, as well as policy implications to increase resilience and adaptation of coastal IAA systems, which could contribute to the understanding of other coastal agricultural deltas around the globe.

2. Data and methodology

2.1 Case study background

2.1.1 Study area. Ben Tre province was the first out of the top ten provinces of Mekong Delta inundated by 1 m sea-level rise, of which approximately 50 percent of the total area was flooded (World Bank, 2010). Chosen research locations were Thanh Phu and Binh Dai commune of Ben Tre province (Figure 1), which were the most vulnerable coastal areas in Ben Tre, with the highest level of poverty (MARD., 2016). People in the area relied heavily on agriculture for their livelihoods, especially in rice culture and recently in IAA farming, adapting to climate change, in particular integrated shrimp cultivation. Indeed, Nguyen *et al.* (2016) suggested that shrimp production helped to alleviate poverty. Moreover, as income increases, the role of aquaculture will be increasingly substantial. The link between IAA farming and poverty alleviation signaled the need for sustainability assessment, especially the rice-shrimp model.

2.1.2 Description of the rice-shrimp farming system. The rice-shrimp culture is an ancient and traditional practice that farmers developed using their resources, and has drawn

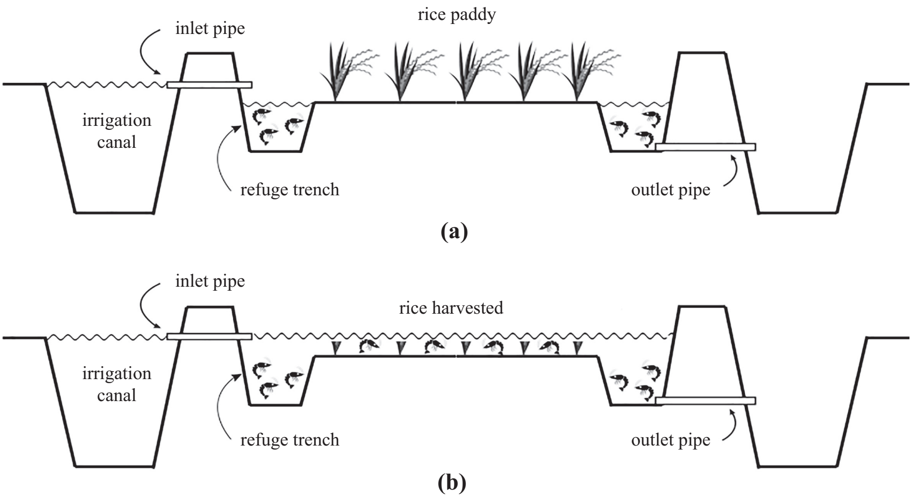


Source(s): Authors own elaboration

Figure 1. Study area of Binh Dai and Thanh Phu District, Ben Tre province, Vietnam

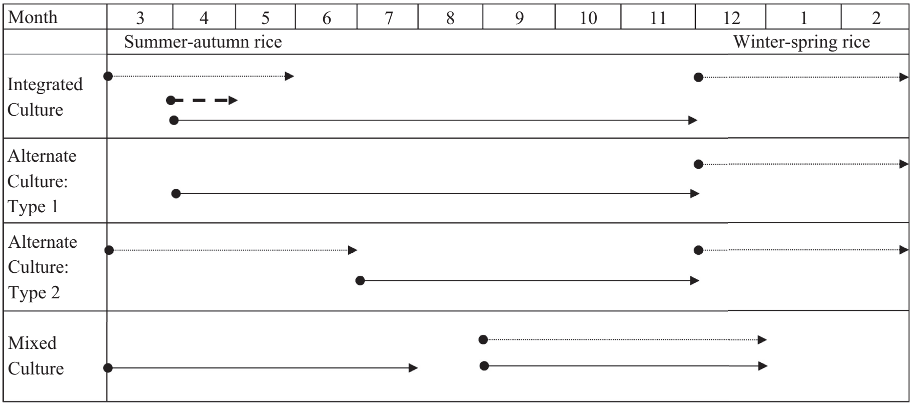
attention from the Vietnamese government as a solution for poverty alleviation of impoverished farmers. Due to the widespread of hatcheries in Vietnam, shrimp cultivation has shifted from wild-caught, juvenile shrimp post-larvae from sluice gates into farms with the help of tides, to acquiring quality-controlled seeds from hatcheries, making the rice-shrimp culture more intensified (Phuong *et al.*, 2006) (See Figure 2).

According to Phuong *et al.* (2006), there are two main forms of rice-shrimp farming: alternate culture model (rotational culture), and integrated culture model (simultaneous culture). Farmers' selection of models depends on their preferences or typical characteristics of the farm. Due to the saline intrusion nature of the research area, most farmers in the area opted for a mixed practice between rotational and simultaneous models. Figure 3 shows the difference in the application of rice-shrimp farming of Ben Tre apart from other provinces in the Mekong Delta (i.e., Vinh Long, Tra Vinh, Can Tho, An Giang, and Dong Thap). In Ben Tre, rice-shrimp culture was employed during the wet season between September and December, and mono-shrimp during the dry season between March and July. In the mixed culture (or as well as simultaneous culture), the rice paddies must be redesigned to adapt to shrimp stocking. In Binh Dai, the surrounding trench is built with a depth of 1.36 $\pm$ 0.94 m, and a width of 5.02 $\pm$ 2.59 m, and that in Thanh Phu, it is 1.35 $\pm$ 1.00 m in depth, and 4.73 $\pm$ 2.26 m in width (see illustrations in Figure 2) along the dike. The total rice farming area of Binh Dai and Thanh Phu is 6,530 $\pm$ 4,120 m^2 and 6,060 $\pm$ 4,020 m^2, respectively. Regarding the total surface water area for shrimp farming, Binh Dai has a slightly larger area of 10,140 $\pm$ 7,300 m^2 than 9,620 $\pm$ 7,050 m^2 of Thanh Phu. During the wet season, rainfall plus the inflow of water from the river helped to flush residual salt from rice fields. Thus, rice-shrimp simultaneous culture was performed. In July, farmers release shrimp seeds into the ditch which provides the refuge for shrimps (*M. rosenbergii*) from the beginning to the rice harvest period (Figure 2a). After the rice is harvested, in December, farmers will provide an influx of water to allow shrimps to



Source(s): Author's own elaboration

Figure 2.
Rice-shrimp farming system. Shrimp shelter in the side trench during rice cultivation (a). After rice harvesting, farmers will open the inlet pipe to flood the field to allow shrimps to eat the leftovers on the rice field (b)



Source(s): Adapted and modified from Phuong *et al.* (2006) for Ben Tre province

Figure 3.
The application of rice-shrimp farming in the Mekong Delta included the current application in Ben Tre province (mixed culture). Periods of shrimp culture are indicated by solid arrows, while periods of rice cultivation are indicated by a dotted arrow. In the integrated culture, the short and heavy dotted arrow indicates the nursing culture

eat the leftover by-products of the rice paddy (Figure 2b). For this model, farmers reported low shrimp productivity due to the small size of harvested shrimps and low survival rates because of trash fish predation.

During the dry season, in March, farmers open the flap gate to allow saline water to flood the field to perform the alternate shrimp culture. The tiger shrimp post-larvae (or *P. monodon*) or sometimes white-legged (or *L. vannamei*) is released at a quite high stocking density of 11.11 ± 5.97 and 10.31 ± 4.96 post-larvae per square meter for Binh Dai and Thanh Phu, respectively. Low survival rates of shrimps because of trash fish predation result in additional batches of complementary post-larvae, around 1.76 ± 0.82 and 1.67 ± 0.77, being released for Binh Dai and Thanh Phu.

It should be noted that different rice-shrimp settings were employed by farmers in other areas. For example, Phuong *et al.* (2006) reported different applications of rice-shrimp farming such as the integrated culture observed in Vinh Long and Tra Vinh provinces, while alternate culture-Type 1 and Type 2 were found in Can Tho, An Giang, and Dong Thap provinces. However, this study only focused on the described practice above, as it is dominant and could also contribute to the common understanding regarding the subject matter.

2.2 Conceptual framework

The World Commission on Environment and Development developed the first guiding principles for sustainable development as "development which meets the present needs without compromising the ability of future generations to meet their own needs" (WCED, 1987). The scientific community generally agreed that sustainable agriculture must sufficiently address multidimensional aspects including economic, social, and environmental objectives. Since then, countless methods have been introduced to access agricultural sustainability; nevertheless, predominant approaches were in favor of indicator-based frameworks (OECD, 2001; Ness *et al.*, 2007). Despite numerous indicator-based frameworks being proposed, there is no "one size fits all" assessment tool. Salient issues arose, associating with the selection of the right framework for the right case study. Compatibility remained one of the essential critera for framework selection (De Mey *et al.*, 2011; Marchand *et al.*, 2014). The compatibility characteristic of a tool is somehow reflected through the role of context-specificity. A generic sustainability assessment framework can successfully address issues related to the environmental dimension; however, it is unable to explain context-specific issues regarding economic and social dimensions (Gasso *et al.*, 2015). Thus, this study first developed a set of guiding principles for framework selection. Due to the aim and scope of the study (Table I) and following Marchand *et al.* (2014), we agreed that the selected framework should:

(1) Fit the aim and scope of the study (Table I).

(2) Be simple but sufficient enough to promote a systematic and structured sustainability assessment.

(3) Have available and correct input data for processing.

(4) Be transparent in assessment phases (calculation, weighing, and aggregation).

(5) Be compatible with existing data systems and local conditions.

(6) Be relevant to use and implement by end-users (i.e., farmers, local authority) (effectiveness).

For the mentioned criteria, the assessment framework of Vanloon *et al.* (2005) was found appropriate for this study, as used in a similar study of Talukder *et al.* (2016), which successfully accessed sustainability of farming systems in the coastal area of Bangladesh.

Criteria	Primary purpose	Level of assessment	Geographical scope	Sector scope	Thematic scope	Perspective on sustainability
Classes	• Research • Policy advice • Farm advice	• Region	• Applicable globally to coastal delta areas	• Applicable to IAA farming systems	• Economic • Social • Environmental	• Mixed perspective (Farm & societal perspectives)

Source(s): Author's own inference based on (Norman *et al.*, 1998; Marchand *et al.*, 2014)

Table I. Aims and scopes of the sustainability assessment of the rice-shrimp integrated farming model

The framework partitioned various dimensions of sustainability into six areas: productivity, stability, efficiency, durability, compatibility, and equity. According to Vanloon *et al.* (2005), six sustainability categories can be distinguished and defined as follows:

Productivity. Any sustainable agricultural systems must be capable of producing high yields to meet the needs of the farm family as well as to contribute to the global food requirements.

Stability. The high level of productivity must be maintained over an extended period. Generally, stability cannot be measured directly, but indirectly via the quality of the resources on which production depends.

Efficiency. In the process of crop production, various resources are required—human, animal, and material—and should be used at their highest potentials to maximize outputs. So, this indicator can be measured in various ways and also be expressed in financial terms.

Durability. Any farming process is often subjected to various stresses (i.e., water, pest). Hence, durability measures whether or not the sustainable system is intrinsically resilient in the presence of such stresses.

Compatibility. In common sense, compatibility implies the ability of an agricultural system to fit in with the surrounding human, social, and natural environments, and at the same time sustain and enhance them. The nature of farming is beneficial to human well-being, but at the same time detrimental to the environment, such as water contamination, loss of biodiversity, or other the collapse of collaborative ecosystems. Therefore, compatibility refers to harmony among all dimensions of sustainability.

Equity. Agriculture should promote a good quality of life among various individuals involved in farming activities and within families. This refers to the consideration for the standard of living, health, and education as well as social welfare for all people in a specific community. Relating to SAFA framework, FAO (2014), this category likely covers economic and social aspects of sustainability, which collaboratively reflects the quality of life.

Often, measuring sustainability performance requires technical data, such as soil nutrients and chemicals. These data were scarce due to finances and time constraints. For that reason, multi-criteria analysis (MCA) was employed as a solution to this problem (criterion 3). To further clarify the transparency of the assessment (criterion 5), this research followed the sustainability evaluating protocol of van Asselt *et al.* (2014). By combining qualitative and quantitative approaches, this study expected a more comprehensive result due to the inclusion of all related indicators, which might be bypassed in the case of data unavailability.

2.2.1 Sustainability assessment protocol. The sustainability assessment was consulted by a group of five experts from Nong Lam University. They were also independent research members of a climate change adaptation project in the Mekong Delta. Experts are specialized in a wide range of related disciplines covering all three dimensions of sustainability, namely, economic, social, and environmental. Due to objective reasons, it was difficult to involve a governmental official. Thus, an expert in coastal agriculture was set out to play a role as a policymaker. Note that, he worked closely with the local authority in numerous past projects. Therefore, he was responsible for policy-related consultation. According to the assessment protocol of van Asselt *et al.* (2014), after defining the case study with the involvement of researchers and policymakers guided by a set of four criteria (i.e., measurability, sensitivity, case, and theme relevant), the gross list of indicators will then again be assessed based on additional five filtering criteria (i.e., min indicators per dimension, indicator for profitability, indicator for societal support, indicator coverage, data availability) to establish the core list of indicators with the assistance of literature and expert opinions. To further employ the bottom-up approach, the author also invited two extension agents, who were also rice-shrimp farmers, to explore their knowledge in the local context to merge with expert opinions for the final decision regarding the core list of indicators. At the evaluation step, researchers and policymakers both engage to assess whether or not adjustment was needed and to constitute sustainability limits taking reference from the vast body of literature and indigenous knowledge from the local context. Afterward, experts also advised on the collection of data, relying on the current setting of the assessment and also upon a strong base of literature. It is worth noting that farmers in this step play a role as information providers, but not assessors. Particularly in this study, the author ignored the last step of using the weighing tool offered by the protocol, to compute manually to gain not just computation freedom but also to take advantage of local experts on weighings that could be considered more context-based than the rigid approach from the tool. Last, the communication of results was delivered with consultation from both policymakers and the researchers.

2.2.2 Gross list, core list, and evaluation of indicators. The gross list of indicators was defined using the framework of Vanloon *et al.* (2005). Note that indicators must be measurable, sensitive to variations, relevant to the case study, and related directly to the theme (Marchand *et al.*, 2014).

The gross list of indicators was shortlisted to the core list of indicators most relevant to the case study, using predefined criteria including minimum one indicator per dimension: indicator for profitability and societal support, data availability, and large coverage of information (van Asselt *et al.*, 2014). Experts also consider the compatibility and feasibility of indicators for assessing the sustainability of the coastal Mekong area.

For the specified case study, 60 indicators were proposed in the gross list based on literature and discussion with the expert group. A core list of 38 indicators was shortlisted using the mentioned criteria, which was discussed with the policymaker (Table AII). Sustainability limits of continuous indicators were set based on legal norms, policy targets, or best performance (Table AIII). Also, linear interpolation was used to convert data to the scale of 100 based on the three defined sustainability limits. Then, the core list of indicators was discussed with the policymaker to double-check on the relevance to the case study.

2.2.3 Sustainability limits. To evaluate whether or not an indicator value is sustainable, sustainability limits are compulsory. There are three levels of limits including non-sustainability, mid-sustainability, and sustainability. Limits were calculated based on available legal norms, policy targets, or best performing values. Interpolation and extrapolation were employed to calculate the required limits depending on available and retrievable limits. When only non-sustainability and sustainability limits were available, the mid-sustainability limit was calculated as the geometric mean of the two assuming lognormal distribution (van Asselt *et al.*, 2014). Due to the inclusion of qualitative indicators, sustainability limits were only used for continuous indicators. For qualitative measured indicators using the MCA approach, the use of the scale between 1 "worst" to 10 "best" already implied worst and best limits, similar to non-sustainability and sustainability limits. Thus, assigning limits was not necessary for those indicators.

2.2.4 Data collection. Data were collected from both primary and secondary sources. To avoid bias from missing out stakeholder participation, this study incorporated both top-down (expert elicitation) and bottom-up (stakeholder) approaches (Binder *et al.*, 2010). A total of 33 farmers from Thanh Phu commune and 25 farmers from Binh Dai commune were surveyed through a structured questionnaire in September 2018. Targeted local farmers must possess at least one year of farming experience and remain with IAA farming at the time of the survey. Two local extensionists and seven enumerators were appointed to assist the data-collecting process. Raw data were pre-processed at the end of the day to make sure information's correctness and to avoid missing data. Also, to simplify the scoring process, the researcher examined and adjusted scores from farmers in case of inconsistency and misclassified data.

2.2.5 Aggregation and weighting. Weighting is popular in conducting a sustainability assessment. Studies use weightings to address the importance of indicators, subthemes, themes, or dimensions. Weighting also serves to mitigate the conflict between global and local applicability. Thus, weighting can be applied from indicator to dimension level, for example, SAFA, FAO (2014). Some assessment frameworks assigned maximum values to weighting at the indicator level, for example, IDEA, Zahm *et al.* (2008).

To comply with criterion 4, this study conducted weighing and aggregation manually in a stepwise manner. First, weights were assigned by experts based on the aim and scope of this study, their understanding, and their judgment of how each component contributes to the final sustainability development at the community level. To simplify the weighting process, experts only weighted the importance of components at the theme level, which meant that all indicators were judged as equally important. A similar practice was performed in RISE 3.0, Grenz, Jan *et al.* (2016, p. 9), and SAFA, FAO (2014). The weights were constrained in a scale of 0–100 percent, of which the total weights of all themes equal 100 percent. Similar to the recommendation on influencing levels of sustainability components of Norman *et al.* (1998), experts' weightings were in favor of the social and economic dimension at the community level. Productivity, compatibility, and equity were equally important (score of 15 percent), while efficiency and durability were scored equally higher at 20 percent. For simplicity, each indicator under each theme was treated with equal importance. Second, before the aggregation, indicator values were converted to the scale of 100 against the predefined sustainability limits (van Asselt *et al.*, 2014). In the case of qualitative indicators, data were amended to the scale of 100 accordingly. Third, data were converted to a same scale (100 points) to facilitate aggregation and comparison between indicators. Then, each theme score was calculated using the arithmetic mean of indicators predetermined under that specific theme.

The last step was the aggregation of theme scores with accordant weightings to calculate the final sustainability index. The calculation of overall sustainability index of each region (i.e., Binh Dai and Thanh Phu communes) can be formulated as:

$$v(x) = \sum_{i=1}^{n} w_i v_i(x_i) \tag{1}$$

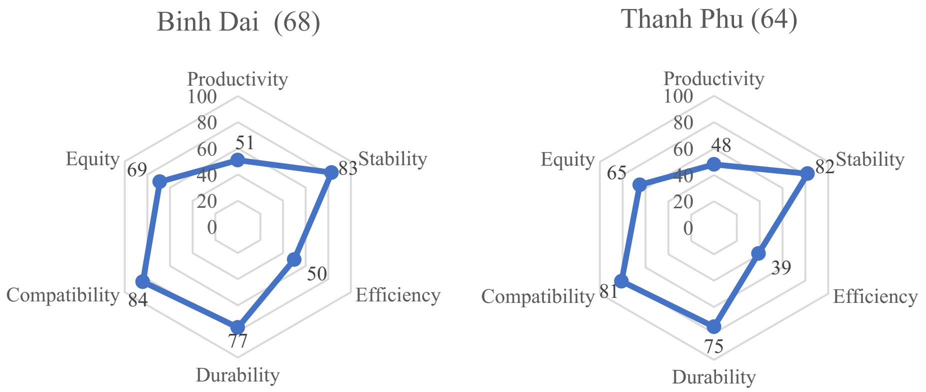
where v is a value aggregation function of score value x_i, n is the number of themes, w_i is the weight of each theme i, and $v_i(x_i)$ is the aggregation score of theme i. The value function $v_i(\cdot)$ gets normalized value between 0 and 100, and the weights w_i get values between 0 and 100 percent, summing up to 100 percent.

3. Results and discussion

The overall sustainability scores were computed based on Eqn 1; thus, the scores of Binh Dai and Thanh Phu communes were 68 and 64, respectively. Comparing the sustainability of the rice-shrimp farming system of the two communes, Binh Dai commune was prominent in every aspect of the assessment. However, there was still plenty of room for improvement for both communes. Major improvements should be considered for productivity, efficiency, and equity themes, whilst minor improvements can be made for stability, durability, and compatibility themes (see Figure 4–10)

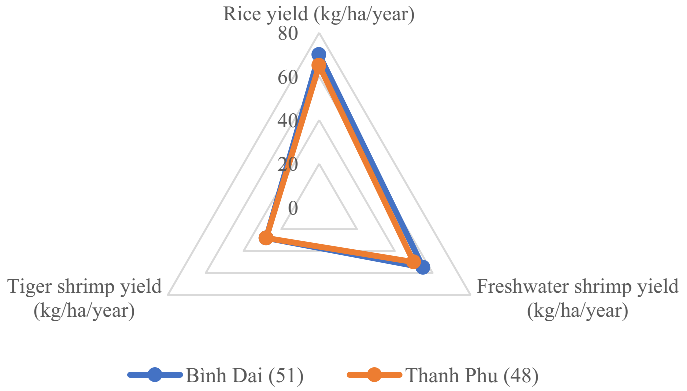
3.1 Themes assessment

3.1.1 Productivity. The average rice yield of Binh Dai and Thanh Phu was 5.4 tons/ha and 5.1 tons/ha, respectively. These were considerably higher than the average rice yield of Ben Tre province in 2017, which was 4.1 tons/ha; however, they were lower than the average rice yield of the Mekong River Delta in 2017, which was 5.6 tons/ha (GSO, 2017). This yield was possible due to climate-adapted crop scheduling (between August and December). Even though, the research areas belong to the brackish zone (salinity level 0.4–18‰), however,



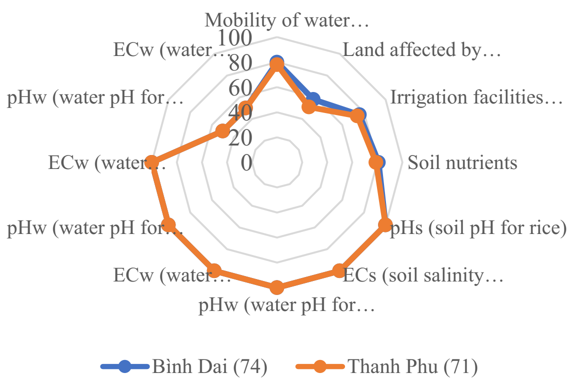
Note(s): Data are presented in percentage, the overall indices are in parentheses

Figure 4.
Sustainability performance of Binh Dai and Thanh Phu communes



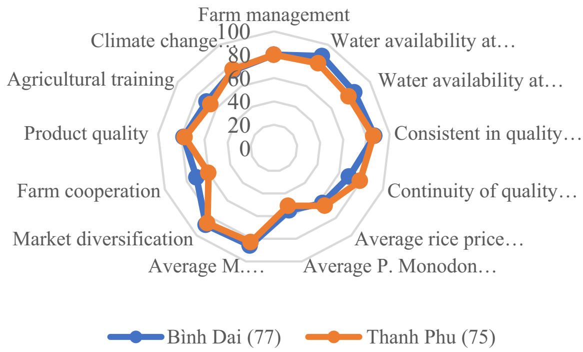
Note(s): Numbers in the legend's brackets are the overall sustainability index at theme level

Figure 5.
Productivity theme assessment of Binh Dai and Thanh Phu communes



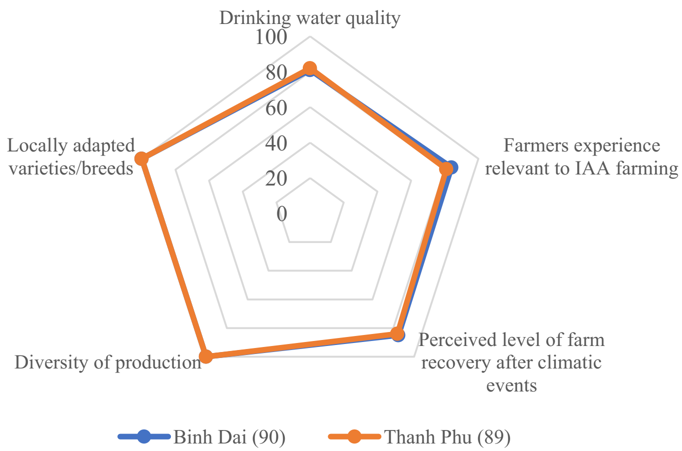
Note(s): Numbers in the legend's brackets are the overall sustainability index at theme level

Figure 6.
Stability theme assessment of Binh Dai and Thanh Phu communes



Note(s): Numbers in the legend's brackets are the overall sustainability index at theme level

Figure 7. Durability theme assessment of Binh Dai and Thanh Phu communes



Note(s): Numbers in the legend's brackets are the overall sustainability index at theme level

Figure 8. Compatibility theme assessment of Binh Dai and Thanh Phu communes

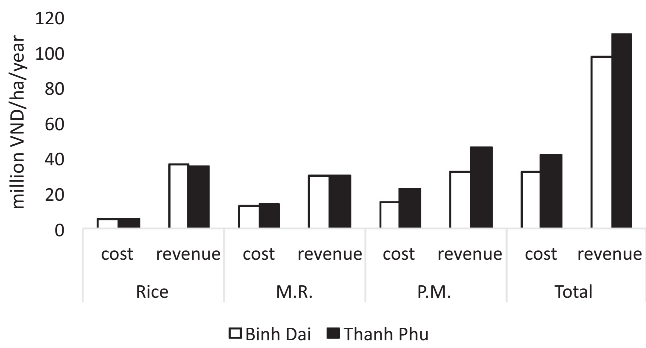
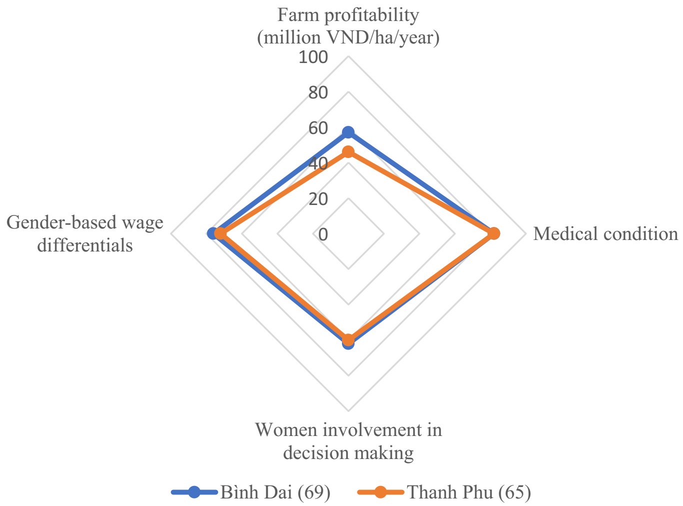


Figure 9. Average benefit cost structure of rice-shrimp system



Note(s): Numbers in the legend's brackets are the overall sustainability index at theme level

Figure 10. Equity theme assessment of Binh Dai and Thanh Phu communes

during the wet season, the residual salt from rice fields was flushed by rainfall and inflow of water. This created a suitable condition for rice-shrimp farming to be employed with a suitable pH and EC for soil and water (see Table AIII and Table AIV). Additionally, thanks to the promotion of local authority, the widespread use of drought- and salinity-tolerant varieties (e.g., OM 6162, Dai Thom 8, Nang Cha) helped to achieve high yields, thus adapt to climate change. Moreover, early rice harvesting in December helped to avoid prolonging the crop to the high salinity periods of late March and April (CCAFS, 2016). Low productivity scores were greatly affected by the low scores of freshwater shrimp and tiger shrimp yield. Numerous potential reasons for such low yields were identified as high stocking density, trash fish issues, and feed management (e.g., commercial feed, fresh feed from snail and trash fish, or mixed feed). Lan *et al.* (2006) reported that freshwater shrimp yield in the integrated farming system ranges between 400–1,680 kg/ha at stocking densities of 2–6 SL/m^2, while the stocking densities of local farmers ranged between 5–21 SL/m^2. High stocking densities were the solution for farmers facing the trash fish issues. Rather than helping, high stocking densities worsened the situation, resulting in low survival rates due to lack of dissolved oxygen for shrimps and small shrimp sizes at the time of harvest. Similar to *M. rosenbergii*, *P. monodon* cultivation has had the same issues. For rotation crop in the case of *P. Monodon*, Truong (2017) suggested that the stocking densities of 7 SL/m^2 would yield 360–400 kg/ha/crop. Thus, the productivity of shrimp cultivation in Thanh Phu and Binh Dai required proper attention to max out its potential (See Table AV)

3.1.2 Stability. The research areas in Thanh Phu and Binh Dai communes were both brackish water zones. Salinity intrusion emerges as a key factor in affecting the stability of farming systems in the areas. Similar pH and EC patterns were observed between the two communes. Water and soil EC were low at the beginning of the rice crop at 0.4 dS/m and 0.27 dS/m, respectively, and increased gradually to 25.1 dS/m and 6.57 dS/m, respectively, at the beginning of the *P. monodon* crop in March; however, thanks to the leaching effect of rainfall at the beginning of the rainy season in June, water and soil EC tended to decrease afterward (Hoa *et al.*, 2016). Besides, the pattern of water and soil pH was evaluated as suitable for rice-shrimp farming. Water pH in the canal varied from neutral to mild alkaline (7.21–8.46), suitable for rice-shrimp farming. Soil pH ranged from mildly acidic to nearly neutral (5.34–6.3). In the rice and *M. rosenbergii* simultaneous crop (July to December), the pH value of soil ranged from mild acidic to nearly neutral (5.34–6.19) (Hoa *et al.*, 2016). The pH and EC of water and soil increased drastically during the *P. monodon* crop (March to July) due to farmers accessing an influx of saline water to perform the alternate shrimp culture. Ben Tre province was also identified as most affected by drought (CCAFS, 2016). The severe drought, due to low water discharge from upstream of the Mekong river and the rising sea levels, resulted in the decrease of groundwater levels and the more extensive salinity intrusion. Several measures were taken in response to climate change. From 2011 until now, asystem of dikes and sluice gates was built and maintained to control salinity intrusion (Can, 2015). Thus, the mobility of water and irrigation facilities was highly appreciated by local farmers in terms of climate adaptation. However, Ben Tre district's DARD reported that salinity levels, for the first time in 2016, reached its peak two months earlier, instead of March and April, and intruded beyond the dikes further inland and also extended its duration in the dry season (CCAFS, 2016). Therefore, climate monitoring and early warning systems play an important role in mitigating the negative impacts of climate change, improving the stability of the rice-shrimp model in the Mekong Delta.

3.1.3 Efficiency. Efficiency was measured by the monetary efficiency of the system. The average monetary efficiency of Binh Dai and Thanh Phu communes was 3.48 and 2.83, respectively. The average benefit-cost ratio (BCR) of rice, freshwater shrimp, and tiger shrimp were 9.85, 2.4, and 3.22, respectively. The BCR of rice was significantly higher than expected. This was achievable for two reasons. First, to grow shrimps, farmers must adopt the organic practice of using no pesticide or insecticide. Therefore, the output rice was considered organic and resulted in a higher price and demand. As observed, Thanh Phu organic rice was bought by companies at the price of 8,500 VND/kg. Compared to 2012–2013, the price of organic rice in Thanh Phu doubled with stable outputs. Furthermore, the National Office of Intellectual Property, under the Ministry of Science and Technology, has granted "lúa sạch Thạnh Phúh (clean rice Thanh Phu) trademark to local farmers since 2016. This granted evidence on the sustainable path of the current farming system. However, farmers in this study are still at their beginning to adopt the practice. Hence, the quality of product outputs (i.e., rice and shrimps) still requires much improvement to meet the standard of the market to achieve a higher price. For that reason, the current output price, let us say rice of 6,500 VND/kg (Binh Dai) and 6,800 VND/kg (Thanh Phu) in this study, signaled the potential for improvement to meet the market standard to obtain higher prices.

Second, the effluent waste of the shrimp culture left a nutrient-rich environment ready for the rice crop; thus, fertilizer cost can be saved. Additionally, farmers' long-lasting experience was dedicated to growing rice rather than shrimps, which resulted in better rice yields than shrimp yields. Indeed, the yield, as well as quality of shrimps, remained a problem in the study sample, which was the reason why farmers can only sell, let us say, *M. rosenbergii* of 145,606 VND/kg (Binh Dai) and 141,600 VND/kg (Thanh Phu), while the market price for organic *M. rosenbergii* was 250,000–300,000 VND/kg reported by local extension agents. In comparison with other sustainability themes, there is plenty of room for improvement of the efficiency of the rice-shrimp system. Especially farmers and the local authority should pay more attention to ameliorating the efficiency of shrimp cultivation.

3.1.4 Durability. The durability of the rice-shrimp farming system in Thanh Phu and Binh Dai communes derived partly from the practice of no chemical pesticide or insecticide. Instead, farmers used biological insecticides from herbs and probiotic products in response to pest stress. Additionally, the sludge, which contained microorganisms, algae, leftover shrimp feeds, and shrimp manure settling down at the bottom of the trench, after shrimp harvest, was pumped to the surface of the rice field. This layer of the sludge discharge, after being dried in the sun, becomes a nutrient-rich and sustainable soil for rice. All farming practices together helped to facilitate farm management peculiar to Thanh Phu and Binh Dai. Thus, the average farm management score of 7.96 for both communes reflected farmers' perception of a fairly high level of ease and convenience for the current system. Also, the cooperation between farmers, and between farmers and local extensions, made the system more durable. Via agricultural trainings, local extensions helped to transfer knowledge and experiences among farmers. Local extensions applied an innovative approach of frequent river water measurement, which indicated water quality (i.e., pH, salinity level) and suitable timing to inform farmers when to draw water into the field. Along with preventing intrusion of saline, the dike system enables water being always available at every stage of the rice cultivation, including sowing and flowering stage. Regarding rice varieties, due to the impact of salinity intrusion and drought, farmers adopted short-cycle varieties integrated with salinity- and drought-tolerant attributes (e.g., OM 6161, Dai thom 8, Nang Cha). Thanks to the combined short and long-term cycles based on climate change, farmers were able to produce better rice yields in comparison to the intensive rice system. However, the problem of the rice-shrimp system emerged from shrimp, not rice. However, the quality and continuity of shrimp post-larvae were stable, provided from trusted hatcheries such as Minh Phu and the Research Institute for Aquaculture No.2. The problem associated with shrimp cultivation could be stocking densities and trash fish issues, resulting in the harvested shrimp sizes varying greatly (37 $\pm$ 15 S/kg) for *P. monodon* and (32 $\pm$ 2 S/kg) for *M. rosenbergii*, which directly affected farmers' revenues due to big differences in prices for smaller sizes. Overall, the rice-shrimp farming system in Binh Dai was more sustainable than that of Thanh Phu in term of durability.

3.1.5 Compatibility. Since the early 1980s, the culture of rice-shrimp farming has developed (Phuong *et al.*, 2006). Since then, the farming system has evolved to cope with changes in the Mekong Delta. The winter-spring crop has shifted to earlier periods from December–March to August–December in response to the shift in the rainfall pattern in the Mekong Delta. Through various severe losses and damages from numerous typhoons and tropical depressions as an impact of climate change, farmers' climate change awareness was strengthened. Thus, along with their past farming experience, farmers in Binh Dai and Thanh Phu have had a better head-start on IAA farming systems due to their relevant skills and knowledge. Indeed, farmers in Binh Dai and Thanh Phu, respectively, have had an average of 8.42 and 8.12 years of experience related to rice-shrimp farming. Comparing the most experienced local farmers, the majority of farmers of Binh Dai and Thanh Phu have accomplished around 8–10 years and 7–10 years of experience, respectively. This could be an inarguable advantage for local farmers to cope with unpredictable climatic events. Similar to the finding of Poelma (2018) in researching the transition of rice-shrimp farming in Kien Giang, rice-shrimp farmers were affected least by changing climatic conditions, whereas rice or shrimp farmers witnessed a lower level of resilience to the impacts of climatic conditions. This study confirmed a perceived positive recovery of rice-shrimp farming against climate change events of Binh Dai (85) and Thanh Phu (84). By definition, compatibility also means sustaining the surrounding environment such as water contamination and loss of biodiversity. The biodiversity aspect of rice-shrimp farming was also investigated with two indicators borrowed from FAO (2014), including production diversity and locally adapted varieties/breeds. Since the rice-shrimp farming model in the research area has been the combination of the alternative and integrative cultures, the nature of the farming model augments crops to be diversified and highly suitable to the goal of sustaining the diversified state of production, which, in turn, has received the maximum score. To cope with climate change (i.e., salinity intrusion), local farmers adopted locally adapted short-cycle varieties integrated with salinity- and drought-tolerant attributes (e.g., OM 6161, Dai Thom 8, Nang Cha) in full, which enhanced the genetic diversity to preserve the biodiversity and the saving of indigenous seeds and breeds. Regarding drinking water quality, the situation was recorded similar to other provinces of the Mekong Delta where drinking water was mostly derived from rainfalls and the underground water (Poelma, 2018). The drinking water in Ben Tre, especially in Thanh Phu and Binh Dai Districts, was exposed to 1–2 dS/m degree of salinity level in both self-drilled wells and protected water pipeline (DWRM, 2016), whereas the total dissolved solids (TDS) level of drinkable water must remain below 1.56 dS/m (or 1,000 mg/l) according to the national technical regulation QCVN 01-11:2018/BYT on the quality of clean water used for domestic purposes. This was not too high above the limit, and was also a good use of rainwater; local farmers still maintained sufficient levels of drinkable water, which contributed to the relatively high scores of drinking water quality of Binh Dai (81) and Thanh Phu (82). For the mentioned reasons, the farming model was considered highly compatible with the research area.

3.1.6 Equity. The overall equity scores of Binh Dai and Thanh Phu were low due to low scores on farms' profitability and women's involvement in decision-making about agricultural activities. The increasing magnitude of average costs for rice, *M. rosenbergii*, and *P. monodon* was 4.74 ± 3.71, 12.36 ± 4.32, and 14.75 ± 11.65 million VND/ha/year, and 5.25 ± 3.23, 13.25 ± 1.84, and 22.27 ± 21.33 million VND/ha/year for Binh Dai and Thanh Phu, respectively. Apparently, the cost of *P. Monodon* varied greatly between the two communes, especially in Thanh Phu. Farmers in Binh Dai performed better in cost control and also in revenue. The average revenue for rice, freshwater shrimp, and tiger shrimp was 35.72 ± 8.42, 29.93 ± 10.64, and 31.45 ± 23.49 million VND/ha/year, and 34.98 ± 8.91, 29.17 ± 12.59, and 45.79 ± 30.94 million VND/ha/year, for Binh Dai and Thanh Phu, respectively.

The medical condition of farmers in the rice-shrimp system between the two communes was highly evaluated due to the adoption of no pesticides, which closely resembled organic practices. Indeed, local authorities are spending efforts to register organic trademarks for the rice and shrimp products of Binh Dai and Thanh Phu. This is very promising to the future productivity of the areas when the price of organic products is 2–3 times higher along with the increasing demand of consumers for safe food. Regarding the gender perspective for agricultural activities, similar to the report of Grassi *et al.* (2017), the rice-shrimp farming system was labor-intensive due to limited machinery involvement; therefore, family labors accounted for the majority of the activities. Besides hired labor, exchange labor—a cost-saving and reciprocal practice (mostly between friends and relatives)—was considered an advantage of the local farming system. The gender division of labor remained aligned with gender roles, in which men were assigned to heavy tasks, while women were mostly assigned to time-consuming light tasks. Because of this perception, women's labor inputs are often considered insignificant to that of men. As a result, women's wages are lower: women receive an average of 120 000 VND/day (US$5.18) for weeding, harvesting, and shrimp-feeding, while men are paid an average of 140 000 VND/day (US$6.04) for rice hauling, mud removing, and shrimp harvesting. Also, women's lack of access to productive resources, such as technology, training, and credit, was likely a factor that made their voices in major household's agricultural decisions undervalued or neglected (Grassi *et al.*, 2017). This study found a similar pattern of women's involvement in decision-making about agricultural activities. The mean scores of women-involvement indices of Binh Dai and Thanh Phu were 6.13 and 6.24, which explained why equity scores of Binh Dai and Thanh Phu were low at 69 and 65, respectively.

4. Conclusion

Agricultural sustainability of the rice-shrimp farming system in Binh Dai and Thanh Phu was assessed by both qualitative and quantitative indicators under six sustainability categories, namely, productivity, stability, efficiency, durability, compatibility, and equity. This study conducted the assessment transparently in a stepwise manner with predefined criteria to ensure the aim and scope of the research topic. The combination of the assessment protocol of van Asselt *et al.* (2014), the assessment framework of Vanloon *et al.* (2005), and the MCA methodology provided a flexible and holistic approach to assess the sustainability level of agricultural systems (e.g., rice-shrimp system). Results from this study shed light on the above-average sustainability levels of rice-shrimp farming systems in Binh Dai and Thanh Phu communes—coastal areas of Ben Tre province, which was severely impacted by climate change. In terms of compatibility, durability, and stability assessment themes, the current rice-shrimp model in local areas showed the potential to cope with climate change. However, major areas for improvements are productivity, efficiency, and equity categories. Several factors could potentially contribute to the low performance of the productivity and efficiency of the rice-shrimp system, including shrimp stocking densities or dissolved oxygen (DO). concentration, trash fish issues, and feed management, which require in-depth technical supports from experts and local extensionists to max out the potential of the local rice-shrimp farming system. Productivity and efficiency of the farming system could be dramatically improved via different mentioned measures, despite current obvious barriers. It should be noted that the farming model might just be at its starting point, and with the help of current cutting-edge technologies and climate adaptive knowledge, foreseeable improvements are surely expectable. Hence, this paper urges the development of the rice-shrimp farming system in the Mekong Delta as a resort to incoming unpredictable climatic events.

5. Policy implications

To increase the adaptive capacities and resilience of the current system, proper government intervention is needed to be in place. Experts recommended the promotion of climate-smart agriculture, such as real-time early warning system, climate adaptive rice varieties, changes in cropping schedule and duration, and climate-related farming knowledge dissemination (CCAFS, 2016). The application of technology in climate-smart agriculture yields positive and potential initial results. Diversification of channels for knowledge dissemination and technology transfer via pilot model, extension training programs, and cooperation programs between farmers and other stakeholders enhances farmers' ability to adapt to climate change in the short- and long-term.

Regarding water management, to cope with the decreasing upstream flows, it is necessary to apply water-saving technologies in upstream provinces (e.g., An Giang, Dong Thap, Tien Giang) to secure sufficient water flow for coastal downstream provinces (e.g., Ben Tre, Tra Vinh). Furthermore, a long-term intervention of upstream flow management requires cooperation between countries occupying upstream of the Mekong river.

Declaration

Data availability statement: The data set used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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List of abbreviations

IAA system	Integrated agriculture-aquaculture (IAA) farming systems are defined as systems sharing resources between aquaculture with agriculture.
P. monodon	Penaeus monodon, commonly known as the giant tiger prawn or Asian tiger shrimp.
L. vannamei	Litopenaeus vannamei also known as Pacific white shrimp or white-legged shrimp.

M. rosenbergii Macrobrachium rosenbergii, also known as the giant river prawn or giant freshwater prawn.

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Appendix

Name of indicator	Measurement	Weight	Data source
Productivity		15	
A. Rice			Questionnaire survey
1. Productivity: grain yield	kg/ha/year		
B. Giant river shrimp (or M. Rosenbergii)			Questionnaire survey
2. Productivity: shrimp yield	kg/ha/year		
C. Giant tiger shrimp (or P. Monodon)			Questionnaire survey
3. Productivity: yield	kg/ha/year		
Stability		15	
A. Landscape			
4. Mobility of water on land	Range from 1 to 10		Questionnaire survey
5. Land surface exposure to saline water	Range from 1 to 10		Government document
6. Land affected by drought in dry season	Range from 1 to 10		Questionnaire survey
7. Irrigation facilities of the land	Range from 1 to 10		Questionnaire survey
B. Soil health			
8. Soil physical properties[a]			
9. Soil texture [a]			
10. Bulk density [a]			
11. Soil chemical properties[a]			
12. Organic material [a]			
13. pH			
14. EC	dS/m		Literature review
C. Soil nutrients			Literature review
15. Digested NPK[a]			
16. Chrome (Cr)[a]			
17. Copper (Cu)[a]			
18. Arsenic (As)[a]			
19. Cadmium (Cd)[a]			
20. Mercury (Hg)[a]			
D. Water			Government document
21. Salinity level of surface water	‰		
22. pH			
23. EC	dS/m		
24. DO[a]	ppm		
E. Other issues			
25. Withdraw of upstream water			Literature review
26. Drying of river[a]			Field observation
27. Stability of embankment[a]			Field observation
Efficiency		20	Questionnaire survey
28. Monetary efficiency	$ outputs/$ inputs		
29. Overall energy efficiency[a]	Energy outputs/ energy inputs		
Durability		20	
A. Resistance to pest stress			Questionnaire survey
30. Chemical response to pest stress[a]	Range from 1 to 10		
31. Farm management	Range from 1 to 10		
B. Freshwater availability			Questionnaire survey
32. Water availability at sowing stage of rice	Range from 1 to 10		
33. Water availability at flowering stage of rice	Range from 1 to 10		
C. Seed			Questionnaire survey
34. Consistent in quality of rice varieties	Range from 1 to 10		

(*continued*)

Table AII. Themes for assessing the sustainability in coastal IAA systems and specific indicators accompanying the case of rice-shrimp farming

Name of indicator	Measurement	Weight	Data source
35. Continuity of quality shrimp seed	Range from 1 to 10		
D. Economics			Questionnaire survey
36. Product price	VND/kg		
37. Market diversification	Range from 1 to 10		
38. Farm cooperation	Range from 1 to 10		
39. Product quality	Range from 1 to 10		
E. Agricultural knowledge			Questionnaire survey
40. Agricultural training	Range from 1 to 10		
41. Soil test before and after production cycle[a]	Range from 1 to 10		
42. Climate change awareness	Range from 1 to 10		
Compatibility		15	
A. Human			Questionnaire survey
43. Illness from drinking water[a]	Range from 1 to 10		
44. Drinking water quality	Range from 1 to 10		
45. Farmers' experience relevant to IAA farming	Range from 1 to 10		
46. Perceived level of farm recovery after climatic events	Range from 1 to 10		
B. Biophysical compatibility			
47. Diversity of production	Range from 1 to 10		Field observation
48. Locally adapted varieties/breeds	Range from 1 to 10		Field observation
49. Overall biodiversity condition: percentage of non-crop area[a]	%		Field observation
50. Overall biodiversity condition: crop richness[a]	Number of crops		Questionnaire survey
Equity		15	
A. Education			Questionnaire survey
51. Educational status of farmer[a]	Years to school		
52. Educational status of farmers' male children[a]	Years to school		
53. Educational status of farmers' female children A	Years to school		
B. Economic			Questionnaire survey
54. Farm profitability	VND/ha/year		
55. Farmer income[a]	VND/ha/year		
C. Livelihood diversity other than agriculture			Questionnaire survey
56. Road networks (establishing farm roads and access roads)[a]	Range from 1 to 10		
D. Health			
57. Medical condition	Range from 1 to 10		Questionnaire survey
58. Sanitation facilities[a]	%		Field observation
E. Gender			Questionnaire survey
59. Women's involvement in decision-making about agricultural activities	Range from 1 to 10		
60. Gender-based wage differentials	Range from 1 to 10		

Note(s): [a]not applicable for the case study

Table AII.

No[a]	Indicator	Sustainability limit (SL)	Mid-sustainability limit (MSL)	Non-sustainability limit (NSL)	Source
Productivity					
1	Rice yield (kg/ha/year)	6,800	4,500	2,200	SL:best practice, MSL: expert opinion, NSL: extrapolation
2	Freshwater shrimp yield (kg/ha/year)	360	200	40	SL:best practice, MSL: expert opinion, NSL: extrapolation
3	Tiger shrimp yield (kg/ha/year)	750	335	150	SL:best practice, MSL: geometric mean, NSL: expert opinion
Stability					
4	Mobility of water on land	10	5	1	
6	Land affected by drought in dry season	10	5	1	
7	Irrigation facilities of the land	10	5	1	
	Soil nutrients[4]	10	5	1	
13	pH_s (soil pH for rice)	5.67.3	7.88.4	< 4; > 8.4	SL: (Kihoro *et al.*, 2013), MSL: (Kihoro *et al.*, 2013), NSL: < 4, (Ali, 2006) and > 8.4 (Kihoro *et al.*, 2013)
14	EC_s (soil salinity level for rice) (dS/m)	< 3	33.8	> 3.8	SL, MSL, NSL: (IRRI, 2015)
22	pH_w (water pH for *P. Monodon*)	7.88.2	6.8	5.9	SL: (Nho *et al.*, 2006), MSL: interpolation, NSL: (Allan and Maguire, 1992)
23	EC_w (water salinity level for *P. Monodon*) (dS/m)	038	45	52	SL:(Motoh, 1981), MSL: interpolation, NSL: (Motoh, 1981)
22	pH_w (water pH for *M. Rosenbergii*)	7.08.5	6.68.7	≤ 6.2, ≥ 9	SL:(Nho *et al.*, 2006), MSL: interpolation, NSL: ≤6.2 (Chen and Chen, 2003); ≥ 9 (Nho *et al.*, 2006)
23	EC_w (water salinity level for *M. Rosenbergii*) (dS/m)	10	17.5	25	SL, MSL, NSL: (Nho *et al.*, 2006)
22	pH_w (water pH for rice)	6.58	88.4	> 8.4	SL, MSL, NSL: (Dobermann and Fairhurst, 2000)
23	EC_w (water salinity level for rice) (dS/m)	< 2	22.6	> 2.6	SL, MSL, NSL: (IRRI, 2015)
Efficiency					
28	Monetary efficiency ($outputs/$ inputs)	10.04	3	0.99	SL: best practice, MSL: geometric mean, NSL: expert opinion
Durability					
31	Farm management	10	5	1	

(*continued*)

Table AIII. Sustainability limits for the case study of rice-shrimp farming

No[a]	Indicator	Sustainability limit (SL)	Mid-sustainability limit (MSL)	Non-sustainability limit (NSL)	Source
32	Water availability at sowing stage of rice	10	5	1	
33	Water availability at flowering stage of rice	10	5	1	
34	Consistent in quality of rice varieties	10	5	1	
35	Continuity of quality shrimp postlarvae	10	5	1	
36	Average rice price (VND/kg)	9,000	5,600	3,500	SL: best price obtained[3], MSL: geometric mean, NSL: expert opinion
	Average *P. Monodon* price (VND/kg)	220,000	144,000	24,000	SL: best price obtained[3], MSL: geometric mean, NSL: min price to breakeven[3]
	Average *M. Rosenbergii* price (VND/kg)	200,000	100,000	50,000	SL: best price obtained, MSL: geometric mean, NSL: min price to breakeven [3]
37	Market diversification[1]	10	5	1	
38	Farm cooperation[2]	10	5	1	
39	Product quality	10	5	1	
40	Agricultural training	10	5	1	
41	Climate change awareness	10	5	1	
Compatibility					
44	Drinking water quality	10	5	1	
45	Farmers' experience relevant to IAA farming	10	5	1	
46	Perceived level of farm recovery after climatic events	10	5	1	
47	Diversity of production	10	5	1	
48	Locally adapted varieties/breeds	10	5	1	
Equity					
54	Farm profitability (million VND/ha/year)	132	62	0	SL: best profit obtained[3], MSL: average profit[3], NSL: no profit.
57	Medical condition	10	5	1	
59	Women's involvement in decision-making about agricultural activities	10	5	1	
60	Gender-based wage differentials	10	5	1	

Note(s): [a]Numbers refer to indicator numbers from Table II
[1]Market diversification is the average of market diversification for shrimp and rice
[2]Farm cooperation is the average of the cooperation between farmers and between farmers and other stakeholders
[3]Data were calculated and round-up from the research data
[4]A qualitative statement of "whether or not soil nutrients were suitable for rice-shrimp farming"; answer varied from "absolutely not - 0" to "absolutely suitable - 10"

Table AIII.

Indicators	Binh Dai (n = 33) Mean	Std. dev.	Min	Max	Thanh Phu (n = 25) Mean	Std. dev.	Min	Max
Rice yield (kg/ha/year)	5,403.03	738.02	4,200	6,800	5,188	718.98	4,300	6,500
Freshwater shrimp yield (kg/ha/year)	216.67	59.86	100	320	201.68	63.38	100	360
Tiger shrimp yield (kg/ha/year)	259.33	197.11	25	750	274.72	186.55	88	714
Mobility of water on land	8	1.63	5	10	7.76	2.38	0	10
Land affected by drought in dry season	5.75	2.47	0	10	5.08	2.62	0	10
Irrigation facilities of the land	7.60	2.31	2	10	7.44	2.46	0	10
Soil nutrients	8.06	1.65	5	10	7.92	2.36	0	10
pH_s (soil pH for rice)[1]	5.84	N/A	5.39	6.3	5.84	N/A	5.39	6.3
EC_s (soil salinity level for rice) (dS/m)[1]	1.73	N/A	0.27	3.2	1.73	N/A	0.27	3.2
pH_w (water pH for *P. Monodon*)[1]	7.75	N/A	7.5	8	7.75	N/A	7.5	8
EC_w (water salinity level for *P. Monodon*) (dS/m)[1]	16.5	N/A	8	25	16.5	N/A	8	25
pH_w (water pH for *M. Rosenbergii*)[1]	7.83	N/A	7.21	8.46	7.83	N/A	7.21	8.46
EC_w (water salinity level for *M. Rosenbergii*) (dS/m)[1]	1.43	N/A	0.4	2.46	1.43	N/A	0.4	2.46
pH_w (water pH for rice)[1]	7.83	N/A	7.21	8.46	7.83	N/A	7.21	8.46
EC_w (water salinity level for rice) (dS/m)[1]	1.43	N/A	0.4	2.46	1.43	N/A	0.4	2.46
Monetary efficiency ($outputs/$ inputs)	3.48	1.28	0.49	6.52	2.83	1.10	1.07	4.83
Farm management	7.96	1.64	4	10	7.96	1.13	6	10
Water availability at sowing stage of rice	8.93	1.19	5	10	8.24	2.33	2	10
Water availability at flowering stage of rice	8.39	1.47	5	10	7.88	2.33	2	10
Consistent in quality of rice varieties	8.72	1.48	4	10	8.6	1.22	5	10
Continuity of quality shrimp postlarvae	6.90	2.55	2	10	7.88	1.66	4	10
Average rice price (VND/kg)	6,506.06	932.04	5,000	8,800	6,832	1,560.90	3,000	10,000
Average *P. Monodon* price (VND/kg)	145,606.1	38,319.33	70,000	220,000	141,600	25,768.2	100,000	180,000
Average *M. Rosenbergii* price (VND/kg)	171,212.1	13,406.52	140,000	200,000	166,000	10,801.23	140,000	180,000
Market diversification	8.80	1.17	6	10	8.62	1.17	7	10
Farm cooperation	7.13	2.58	0	10	6	3.32	0	10
Product quality	7.84	1.66	5	10	7.72	1.59	5	10
Agricultural training	7.03	2.70	1	10	6.64	2.44	2	10
Climate change awareness	7.54	1.92	3	10	7.6	2.16	3	10
Drinking water quality	8.14	1.43	4	10	8.24	1.33	6	10

(*continued*)

Table AIV. Descriptive statistics of sustainability indicators

Indicators	Binh Dai (n = 33) Mean	Std. dev.	Min	Max	Thanh Phu (n = 25) Mean	Std. dev.	Min	Max
Farmers experience relevant to IAA farming	8.42	1.43	5	10	8.12	1.48	6	10
Perceived level of farm recovery after climatic events	8.5	1.19	6	10	8.39	1.2	6	10
Diversity of production	10	0	10	10	10	0	10	10
Locally adapted varieties/breeds	10	0	10	10	10	0	10	10
Farm profitability (million VND/ha/year)	65.24	20.13	29.54	104.47	69.17	36.10	4	125.4
Medical condition	8.24	1.39	5	10	8.24	1.23	6	10
Women's involvement in decision-making about agricultural activities	6.24	2.56	0	10	6	2.48	2	10
Gender-based wage differentials	7.69	1.51	5	10	7.16	1.84	4	10

Note(s): [1]Data were obtained from the study of for the research areas

Table AIV.

Sustainability indicators (SIs)	Sustainability value[2] Binh Dai (n = 33)	Thanh Phu (n = 25)	Weighing[1]
Productivity[a]	*51*	*48*	15
Rice yield (kg/ha/year)	70	65	
Freshwater shrimp yield (kg/ha/year)	55	50	
Tiger shrimp yield (kg/ha/year)	28	28	
Stability[a]	*82*	*81*	15
Mobility of water on land	80	78	
Land affected by drought in dry season	58	51	
Irrigation facilities of the land	76	74	
Soil nutrients	81	79	
pH_s (soil pH for rice)	100	100	
EC_s (soil salinity level for rice) (dS/m)	100	100	
pH_w (water pH for *P. Monodon*)	100	100	
EC_w (water salinity level for *P.* Monodon) (dS/m)	100	100	
pH_w (water pH for *M. Rosenbergii*)	100	100	
EC_w (water salinity level for *M. Rosenbergii*) (dS/m)	100	100	
pH_w (water pH for rice)	50	50	
EC_w (water salinity level for rice) (dS/m)	50	50	
Efficiency	*50*	*39*	20
Monetary efficiency ($ outputs/$ inputs)	50	39	
Durability[a]	*77*	*75*	20
Farm management	80	80	
Water availability at sowing stage of rice	89	82	
Water availability at flowering stage of rice	84	78	
Consistent in quality of rice varieties	87	86	
Continuity of quality shrimp postlarvae	69	79	
Average rice price (VND/kg)	63	66	

(*continued*)

Table AV.
Sustainability indicators' values and overall indexes of rice-shrimp integrated farming system

Sustainability indicators (SIs)	Sustainability value[2] Binh Dai (n = 33)	Thanh Phu (n = 25)	Weighing[1]
Average *P. Monodon* price (VND/kg)	55	51	
Average *M. Rosenbergii* price (VND/kg)	86	83	
Market diversification	88	86	
Farm cooperation	71	60	
Product quality	78	77	
Agricultural training	70	66	
Climate change awareness	75	76	
Compatibility[a]	*84*	*81*	15
Drinking water quality	81	82	
Farmers experience relevant to IAA farming	84	81	
Perceived level of farm recovery after climatic events	85	84	
Diversity of production	100	100	
Locally adapted varieties/breeds	100	100	
Equity[a]	*69*	*65*	15
Farm profitability (million VND/ha/year)	57	46	
Medical condition	82	82	
Women's involvement in decision-making about agricultural activities	62	60	
Gender-based wage differentials	76	72	
Overall index[b]	*68*	*64*	

Note(s): [1]Weighing obtained from expert consultation
[2]Data were normalized to the scale of 100 and rounded up
[a]Rounded average of indicators' values in the same category. [b]Rounded calculated percentage using Eqn 1

Table AV.

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