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RESEARCH ARTICLE

# Aquaculture innovation system analysis of transition to sustainable intensification in shrimp farming

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## Abstract

The shrimp sector has been one of the fastest growing agri-food systems in the last decades, but its growth has entailed negative social and environmental impacts. Sustainable intensification will require innovation in multiple elements of the shrimp production system and its value chain. We use the case of the shrimp sector in the Mekong Delta in Vietnam to explore the constraints in the transition to sustainable intensification in shrimp farming, using an analytical framework based on innovation systems thinking, i.e., an aquaculture innovation systems framework. Using this framework, we conduct a systemic diagnostic of blocking mechanisms, interrelated sets of constraints within the aquaculture sector that hinder a transition toward sustainable intensification. Our findings show that the major constraints are institutional, with limited enforcement of the regulatory framework for input quality control, disease control, and wastewater management, and a lack of coordination between government bodies to design and enforce this framework. At farm level, limited access to capital favors pond mismanagement and the use of low-quality inputs. The absence of multi-stakeholder initiatives to foster dialog between actors in the value chain constrains the response to new regulations dictated by international market demand. Because of shrimp farming's connectivity with the wider ecosystem, sustainable intensification in shrimp farming will require collective management of water resources at the landscape level for disease and water pollution control. Ecological principles for pond management need to be promoted to farmers in order to reduce farmers' inefficient practices and build their capacity to understand new techniques and inputs available in the Vietnamese market. Our paper demonstrates for the utility of a multi-level, multi-dimension, and multi-stakeholder aquaculture innovation systems approach to analyze and address these blocking mechanisms in the transition to sustainable intensification in shrimp farming and aquaculture more broadly.

**Keywords** Aquaculture innovation systems · Sustainable intensification · Sustainability transitions · Socio-ecological systems

## 1 Introduction

Aquaculture systems have become important for the world's food and protein supply and are a key component of agri-food systems, supporting food security (Beveridge et al. 2013) and contributing to national and local economic growth by providing employment and business opportunities (Phillips et al. 2016). Aquaculture systems grew at a pace higher than 7% between 1990 and 2010, and the aquaculture area has expanded and production has intensified across the world. This has happened especially in Asia, where 81% of world aquaculture production is concentrated (FAO 2014). This spectacular growth has not been without environmental, societal, and economic trade-offs (Hall 2004): the expansion of shrimp farming in Southeast Asia in the late 1990s and early 2000s produced negative externalities such as the destruction of mangroves (Hamilton 2013), pollution of local land and water resources (Hatje et al. 2016), and indebtedness and reduced access to land for small-scale farmers (Lutrell, 2006). Negative impacts extend beyond production locations, as intensive production systems are dependent on fishmeal and fish oils used in pelleted feed (Tacon and Metian 2009) and replacement by vegetal proteins and oils such as soybean also has environmental impacts such as loss of biodiversity (WWF 2014).

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Frequently, the sector has faced disease outbreaks, and recently in Southeast Asia, a new disease appeared with significant drops in production in Thailand and Vietnam (Thitamadee et al. 2016). Producers, mostly smallholder farmers, are constantly struggling to adapt to new environmental and disease conditions while responding to consumers' quality demands and being pushed by local government to intensify their production to reach production targets (Jespersen et al. 2014). Although there have been successes in initiating transitions toward more sustainable systems, with for example producers' uptake of quality standards for environmental and social performance (Omoto and Scott 2016), developing a sustainable and resilient sector that can also integrate smallholder producers remains a challenge.

Given that the aquaculture sector in Southeast Asia has strongly intensified with negative consequences, calls have been made to put more effort into making this a process of *sustainable intensification* (Little et al. 2016). The sustainable intensification concept, widely used in agricultural research for development (Wezel et al. 2015), comes from the analysis that food production must be increased to achieve food security, but this must be achieved without negative externalities, adopting a more integrated approach that encompasses the ecological dimension of agriculture (Duru et al. 2015). It has been argued that sustainable intensification requires a range of technological and socio-institutional innovations and the engagement of different stakeholder groups (Struik et al. 2014).

Therefore, to understand pathways for sustainable intensification, an approach is needed that takes into account complex interactions between technological, social, and institutional dimensions (Wigboldus et al. 2016), deploying a systems approach to innovation (Wezel et al. 2015). However, a recent systematic review on approaches to innovation in aquaculture showed that innovation in this field is approached mainly from a technological viewpoint and focuses on understanding reasons for adoption/non-adoption of technologies by individual farmers at farm level (Joffre et al. 2017). Meanwhile, the integration of aquaculture production systems into global value chains, the influence of international standards and national policies on production systems (Tran et al. 2013), and the connectivity of production systems to the wider socio-ecological system (Bush et al. 2010) influence sustainable intensification, calling for a more systemic approach to aquaculture innovation. As Joffre et al. (2017) argue, there has been limited application of systemic assessment models to identify barriers to innovation in aquaculture systems. Given that aquaculture can be seen as a form of animal farming, we deem it appropriate to employ systemic analysis frameworks based on innovation systems thinking as applied in agriculture to assess aquaculture systems (Lamprinopoulou et al. 2014).

We take the shrimp sector in the Mekong Delta in Vietnam (see Fig. 1) as a case to analyze the constraints on transforming the sector toward sustainable intensification. The objective of the paper is to employ an innovation systems analysis framework to first identify the types of constraints to sustainable intensification in shrimp farming and the stakeholders that reproduce those constraints, and then analyze how those constraints are interlinked and create blocking mechanisms that hinder innovation toward sustainable intensification. In Section 2, we present our case study and the methodology used to answer our research questions, before presenting and discussing the results (Section 3) and conclusions (Section 4).

## 2 Material and methods

### 2.1 Case study

In Vietnam, the shrimp farming industry started in the early 1990s, and the cultivated area and production grew from 230,000 ha and 56,000 metric tons in 1991 to 655,000 ha and 487,000 metric tons in 2012 (Hai et al. 2016). Production is localized in central Vietnam and the Mekong Delta. The latter region comprises 90% of the total shrimp farming area (both *Penaeus monodon* and *P. vannamei*) and contributes 75% to national production. Therefore, we focus our analysis on the three main producing provinces in the Mekong Delta (Soc Trang, Bac Lieu, and Ca Mau provinces, see Fig. 2) to include a wide array of production systems, from vertically integrated intensive farms to small-scale extensive producers. The latter type of producers farm 90% of the cultivated area and play a dominant role in total shrimp production (Hai et al. 2016). These three provinces were selected because the objective is to provide a comprehensive picture of the sector, embracing the diversity of production systems, biophysical conditions, and stakeholders, rather than performing a comparative analysis of three case studies.

### 2.2 Analytical approach

We follow ideas from agricultural innovation systems thinking (Lamprinopoulou et al. 2014; Turner et al. 2016), in which innovation is perceived and analyzed as a transformative process of both technological and non-technological (institution, regulatory framework, socio-cultural norms, and culture) changes in agricultural systems. Spedding (1998) defines agricultural systems as operational units of agriculture, including all actors and organizations at local, regional, and national level that are involved in the production, processing, and commercialization of agricultural commodities. Hence, these can be considered the production systems and the broader value chains in which they are embedded. Innovation in agricultural systems take place across different scale levels (e.g., farm, community, region) and often requires constraints beyond the farm level to be resolved in order to create a conducive environment for innovation and on-farm technology adoption

**Fig. 1** Left: Shrimp farmer applying feed in a semi-intensive shrimp production system. Right: Google earth view of the My Thanh River mouth in Soc Trang province, Mekong Delta (Vietnam), in August 2015, illustrating the concentration of shrimp ponds in the landscape

(Struik et al. 2014). Similar to the agricultural sector, aquaculture production systems and value chains, especially for shrimp as an export commodity, are strongly influenced by food safety regulations and product quality, with the development of quality standards. Therefore, even if farms are central to the innovation process, an analysis of the constraints to innovation requires a framework that not only encompasses economic or technical dimensions, but also integrates biophysical, institutional, and market structure dimensions. Innovation is thus the outcome of a multi-stakeholder process of actors linked to those dimensions, involving different value chain actors and their broader regulatory and support environment, which then jointly form an *aquaculture innovation system* (Doloreux et al. 2009; Joffre et al. 2017).

For our analysis, we use an analytical framework based on innovation systems thinking that enables a systematic analysis and classification of well-established categories of constraints (also referred to as weaknesses, failures, or problems) in innovation systems and that connects this with stakeholders that cause or reproduce those constraints (Klein Woolthuis et al. 2005; Van Mierlo and Leeuwis, 2010; Wieczorek and Hekkert 2012). This analytical framework is an iteration in innovation systems thinking building on seminal works such as those of Lundvall (1992), Dosi (2000), and Malerba (2002), which have also fed into the agricultural innovation systems approach (see Lamers et al. 2017, for a more extensive description of the conceptual links). The framework has been extensively used in the agriculture sector to assess innovation as a multi-stakeholder and multi-dimensional process in agricultural innovation systems (Amankwah et al. 2012; Totin et al. 2012; Lamprinopoulou et al. 2014; Kebebe et al. 2015; Turner et al. 2016).

Given the similarities between agricultural and aquaculture production systems and value chains, we deemed this framework appropriate for a multi-dimensional analysis of constraints hindering innovation processes linked to the functioning of the aquaculture innovation system in Vietnam. We use the framework as applied earlier in agricultural contexts, but in this case, the novelty lies in its first application to shrimp farming. Earlier work on aquaculture innovation systems (Doloreux et al. 2009) has focused mainly on analyzing innovation support organizations such as research, extension, and training organizations and has not used this comprehensive analytical framework. A similar framework based on the same

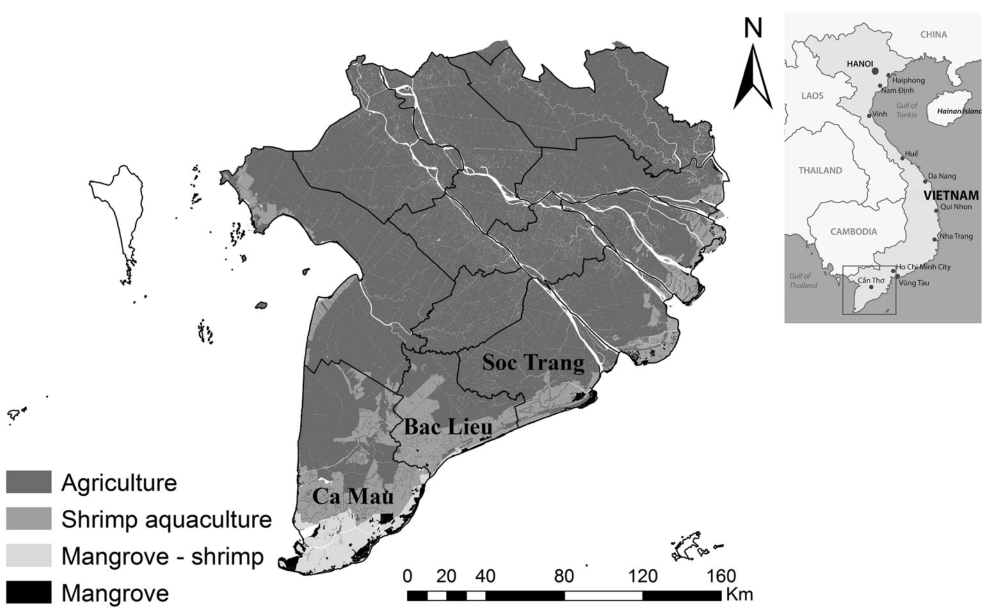


**Fig. 2** Study area (Ca Mau, Bac Lieu, and Soc Trang provinces) in the coastal zone of the Mekong Delta, Vietnam

principles has been used recently in analyzing aquaponics (König et al., 2018).

We adopt a two-step analytical approach. In the first analytical step, the constraints and the reasons behind them are classified in five categories of structural elements that affect the functioning of the innovation system toward a given objective (in this case, sustainable intensification of aquaculture systems), namely constraints in physical and knowledge infrastructures, constraints related to hard and soft institutions, and constraints in interactions and market structure (Table 1). These constraints may refer to lock-in of the current system and rigidity toward change, or to deficiencies in the organization of innovation. Using an analytical framework that includes these categories of constraints allows a systemic analysis of constraints, not limiting the analysis to just a technical or socio-economic dimension. Recent studies in the aquaculture sector show the importance of also including institutional and biophysical dimensions in aquaculture (see Joffre et al. 2017, for a review).

The combination and interactions of constraints can generate systemic lock-in through so-called blocking mechanisms, which are causal loops of constraints (Turner et al. 2016; Wesseling and Vooren, 2016). Therefore, in the second analytical step, we analyze the change capacity of the shrimp innovation system, looking at how the identified constraints interact and generate blocking mechanisms that negatively influence the sector in its transition toward sustainable intensification.

### 2.3 Data collection

We used the Rapid Appraisal of Agricultural Innovation System (RAAIS) stakeholder workshop methodology (Schut et al. 2015) to collect information. We translated the RAAIS method previously used in agriculture to aquaculture (i.e., Rapid Appraisal of Aquaculture Innovation System), where aquaculture is defined as the farming of aquatic organisms (fish, mollusks, crustaceans, and aquatic plants) and includes rearing processes and husbandry techniques as in other types of animal production. RAAIS is a participatory assessment tool that aims to identify constraints to innovation and includes three components: (i) a multi-stakeholder workshop, (ii) in-depth interviews with different stakeholder groups' representatives, and (iii) secondary data collection to complement the analysis. The workshop, held in Can Tho University on May 18, 2016, included 22 representatives of six different stakeholder groups: intensive farmers (2), extensive farmers (6), government representatives (2), NGOs and civil society (3), the private sector (5), and research and training (4). The starting point of the workshop was to identify the constraints and opportunities for sustainable intensification of aquaculture production systems. The stakeholder groups were guided through a series of participatory exercises to identify, in each group, the top five constraints to achieving sustainable intensification in shrimp farming. The top constraints selected by each group were then grouped into four main problematic issues during the workshop. The grouping resulted from a consensus among the different stakeholder groups and was facilitated by the research team during a participatory exercise. The names chosen for those problematic issues were refined later during the analysis. From May to July 2016, 32 individual in-depth interviews were conducted with key informants from those stakeholder groups (3 intensive farmers, 6 extensive farmers, 7 government representatives, 7 NGOs and civil society, 6 private sector, and 3 research and training) to deepen our understanding of the shrimp sector, validate and triangulate the results from the workshop, and identify the underlying causes of the constraints highlighted during the workshop. During both the workshop and the individual in-depth interviews, selected stakeholders were either from the three coastal provinces or operating at sub-national level (researchers, NGOs, private sector) in order to provide a holistic view of the sector. In addition, secondary data in legal documents, regulations, plans for shrimp farming development, and socio-economic data and data on the study sites were collected to strengthen, validate, and triangulate the workshop and interview results.

**Data availability statement** All data are available upon request to the authors.

## 3 Results and discussion

### 3.1 Constraints to sustainable intensification and underlying causes

In this section, the analysis focuses on the constraints and underlying causes that hinder innovation toward sustainable intensification, before we discuss how those constraints interact to generate blocking mechanisms (Section 3.2). The analysis is based on the main constraints identified during the workshop, complemented with in-depth interviews that provided information on underlying causes of the identified constraints as well as relationship between constraints. When appropriate, our analysis was complemented with secondary data from literature. Our analysis reveals that the main problematic issues affecting shrimp producers and sustainable intensification are technical, biophysical, market, and socio-cultural. Using the analytical framework, we identify and classify the constraints relating to these problematic issues and their underlying causes in various parts of the system and produced/reproduced by different stakeholders (Table 2).

#### 3.1.1 Water quality and climate variability

According to stakeholders, the constraints affecting shrimp farming include recent climatic variation with strong diurnal

**Table 1** Categories of constraints relating to structural elements of the innovation system that hinder innovation (Klein Woolthuis et al. 2005; Van Mierlo and Leeuwis, 2010)

| Structural element | Constraints |
|---|---|
| Infrastructure | Physical (road, canals, railroad, electricity network) and knowledge infrastructure (extension and R&D centers for example). Infrastructures can be absent or unsuitable for the current context, needs, and challenges. The cost of developing, improving, or adapting those infrastructures is too high and cannot be made by individual system actors or cannot change rapidly, thereby hindering innovation. In the case of a natural resource-based sector like aquaculture, this may also include the ecological infrastructure. |
| Hard institutions | Formal rules, laws, regulations, and sector strategies that are either missing, malfunction, or are not well coordinated. Lack of regulation or lack of regulation enforcement hinders innovation by supporting existing (bad) practices. Too rigid policies or rules constrain innovation because they constrain the development of novelties. Absence of coordination of regulatory frameworks can result in inefficient enforcement, failing to support innovation by favoring the status quo, or causing uncertainty for innovation actors. |
| Soft institutions | Values, unwritten rules, and norms illustrated by: "the way business is done," keeping actors in repetitive practices and habits hampering change. They may also affect collaboration for innovation. |
| Interactions | Either a too strong or a too weak interaction between actors. With too strong interactions, actors are locked into relationships that hinder new ideas and exclude potential new collaboration. Conversely, weak interaction relates to unconnected (or not well-connected) actors preventing knowledge exchange and the combination of knowledge and resources. These two constraints indicate the need for balanced interactions, between openness and closure, informal or formalized interactions, trust relationships or contracts. |
| Market structure | Value chain organization and relations between actors such as monopoly, lack of transparency, or inefficient market knowledge sharing between actors can hinder initiatives. |

temperature variation increasing risk of disease in ponds, water pollution from upstream rice and shrimp farms, high water salinity concentration, and waterways that are not fit for purpose, limiting access to, and quality of, water for aquaculture in specific areas. Rapidly changing climate conditions and climate events are difficult to predict and it is difficult to mitigate their effects on shrimp ponds, but water quality deterioration results from various constraints that perpetuate this situation and make it hard to change.

A first constraint relates to local conditions for raising shrimp, which is highly dependent on water quality. Stakeholders indicate that shrimp farms discharge heavy loads of nutrients into the canals, as well as water contaminated with disease, leading to the continuous presence of diseases in waterways. Inadequate land-use planning with high concentrations of intensive farms, combined with waterways that are too small in specific areas, increase water pollution. This problem is accentuated by the landholding structure, with numerous small-scale farms of less than 0.5 ha unable to allocate 30% of their land to a water treatment pond.

A second constraint concerns regulatory framework enforcement. Rules exist for water treatment and disease control, but those rules are not properly enforced by local extension services (one staff member per district) due to lack of capacity to control all farms in areas with a high density of intensive farming. A similar lack of regulation enforcement applies to disease management. In the event of a disease outbreak, farmers have to report to the local Department of Agriculture and Rural Development (DARD) for diagnostics to decide on treatment. However, complying with this rule increases farmers' operational costs, and farmers might lose the benefit of an early harvest in the event of mass mortality in the pond. Therefore, farmers rarely report diseases to DARD, thereby limiting the effectiveness of a disease management plan based on biosecurity control measures. There is also a laissez-faire attitude, with an administration not inclined to fine a farmer who is already struck by a disease in his/her pond and who already faces financial issues.

#### 3.1.2 Low quality of inputs and post larvae

Access to inputs is not problematic. However, input quality suffers from a lack of enforcement of regulation concerning not only the accessibility of banned products such as certain types of antibiotics (chloramphenicol, nitrofurans, fluoroquinolones, and quinolones being the most common), but also the quality control of inputs sold (vitamins, additives, probiotics, and antibiotics).

A first constraint concerns access to banned products because of inadequate regulation. Decree 178 (2013) on sanctions against administrative violations relating to food safety stipulates fines between 20 and 50 million VND for the use of banned chemical products or additives. Local authorities and exporters consider that this fine is not large enough in comparison to the potential financial benefits of selling those banned products. Recently, the decree has been revised, and, since mid-2016, infringements fall under the Criminal Procedure Code and entail jail time. This type of sanction is expected to induce a change in the behavior of current offenders.

**Table 2** Constraints to sustainable intensification in shrimp farming in the Mekong Delta (Vietnam), underlying reasons, and stakeholder group producing/reproducing them

| Problematic issue selected by stakeholders | Constraints connected to problematic issue | Underlying reason for constraint | Type of constraint | Stakeholders related to, causing, and reproducing the problematic issue |
|---|---|---|---|---|
| Unpredictable climate conditions and water pollution | Waterway unfit for purpose<br>Lack of land for water treatment | Inadequate land-use planning | Infrastructural<br>Hard institutional | Government<br>Farmers |
| | Lack of enforcement of rules regarding water discharge | Lack of capacity | Hard institutional | Government |
| | Individualist behavior regarding disease and waste management | Additional cost | Soft institutional | Farmers |
| Low quality of inputs and post larvae | Weak enforcement of regulatory framework | Lack of capacity and infrastructure<br>Complex regulatory framework and overlapping responsibilities | Hard institutional<br>Infrastructural<br>Interactional | Government Suppliers |
| | Access to banned products | Lack of capacity to enforce regulation | Hard institutional | Government<br>Farmers<br>Suppliers |
| Mismanagement and local practices | Low farmer awareness regarding standard requirements, pollution, and pond ecology process | Lack of knowledge transfer<br>Policy focus on productivity target and intensification | Interactional<br>Knowledge<br>Infrastructural<br>Hard institutional | Farmers Government<br>Private sector advisors |
| | Farmers' limited trust of extension and private sector service providers | Lack of exchange and dialog<br>Private sector's vested interests | Soft institutional<br>Interactional | Government<br>Farmers<br>Suppliers<br>Private sector advisors |
| | Limited access to credit | Too high risk for financial sector | Hard institutional | Credit providers |
| Market knowledge and export requirements | Absence of mechanisms to mitigate market price fluctuations | International market difficult to regulate | Hard institutional | Government |
| | Lack of coordination between value chain actors to establish quality standards and facilitate market access to smallholders | Limited infrastructure to support joint learning and cooperation<br>Numerous actors and producers to organize | Interactional<br>Knowledge<br>Infrastructural | Government<br>Processors<br>Farmers<br>Exporters<br>Traders |

A second constraint concerns the less-than-perfect implementation of input quality regulation. Inputs (feed, probiotics, antibiotics, and other additives) are sold through 1799 registered retail shops, and thus considerable resources are required to control both production and retails shops regarding the quality of the inputs reaching the market. In addition, regulation is complex, with overlapping responsibilities, because three ministries—the Ministry of Agriculture and Rural Development (MARD), the Ministry of Health, and the Ministry of Industry and Trade—design and issue specific implementing regulations. The MARD alone has released 19 circulars regulating food safety, and the Ministry of Health has brought in 15 legal documents guiding the Law on Food Safety (2010) and 54 national technical regulations on food safety.

Similar inefficient quality control is found for post larvae (PLs), with non-disease-free PLs present on the market. In the Mekong Delta, there is an estimated infection rate of around 54%, and only 38.5% of the PLs are tested for disease before stocking (Hai et al. 2016). The regulatory framework for the control of PL quality and the operation of hatcheries is well designed, with standard procedures, control stations at provincial and district level, and a dedicated department within provincial DARDs to implement control. The underlying reason for the gap between existing rules and their enforcement lies in limited infrastructure and limited knowledge and capacity in the responsible department. Human resources—one DARD staff member per district and one per commune—and laboratories were inadequate to control the 90 billion PLs produced by 1750 hatcheries in the country in 2015. At local level, DARD staff members have to control imports from other provinces with for example 19 billion PLs imported by truck every year into Soc Trang province. In addition, they have to control PLs locally produced in numerous small-scale hatcheries. In Ca Mau province, 40% of 16 billion PLs are produced locally in 870 hatcheries.

The laboratories necessary to control PL quality are not sufficient in the growing area or are located too far away from farms, increasing the overall production cost for small-scale farmers. As an example, the test for white spot syndrome virus costs 7 USD or 160,000 VND/sample, not to mention the additional transport cost to the laboratory. In the in-depth interviews, the limited technical capacity of laboratory staff was indicated as a constraining factor. Farmers do not trust the certification of disease-free PLs, which is supposed to guarantee the quality of the product for buyers. Like the other inputs, PL quality suffers from inadequate infrastructure and hard institutional constraints. These constraints take the form of weak enforcement of a regulatory framework that does not reflect the current context and that would require more efficient control systems and a major investment to upgrade the capacity of the institutions in charge of quality control.

#### 3.1.3 Pond (mis)management and local practices

A first constraint concerns training that is more oriented toward the use of inputs to control disease and increase productivity and less oriented toward pond ecology principles and sustainable intensification. One cause of this productivity orientation is national policy, which aims to achieve increasingly high production targets, with for example the 2013 plan for aquaculture aiming at shrimp production of 700,000 metric tons in 2020 (about 500,000 metric tons in 2013) and a revenue of 10 billion USD (Decision 1445/2013/ QD-TTg). These targets push provincial and district level authorities to intensify production. Government research programs are oriented toward intensification of production systems, and limited research and interventions focus on other dimensions of shrimp production (pond ecology, market, or value chain organization). A recent study by Boyd and Engle (2017) in Vietnam reveals that more than 90 different types of inputs used by shrimp farmers, several of which are banned, do not have proven effects on the pond environment and yet still increase production costs. According to stakeholders, farmers' capacities to critically assess new technologies and to choose a technology (or a type of input) are challenged by the diversity of products available on the market and sometimes by contradictory messages from diverse suppliers.

A second constraint relates to the limited trust in private sector advisors because of their interest in selling products. Farmers' limited capacity and knowledge in relation to pond ecology induces misuse of products and pond mismanagement, according to interviews with local extension services, the private sector, and farmers. The limited interactions between researchers and farmers, as well as the lack of infrastructure facilitating farmers' access to knowledge, limit the trust between knowledge providers (extension services, private sector advisors) and farmers.

Finally, pond mismanagement and the use of low-quality inputs are influenced by the lack of access to credit. Although infrastructures to access credit are in place, farmers' access to credit is in practice limited. After the golden age of shrimp farming in Vietnam and the frequent failures due to diseases, private banks are now stricter about providing loans to farmers. For example, 70% of shrimp farmers' land is under mortgage in Bac Lieu province, and farmers need to be reasonably literate to develop a full proposal to submit to the bank. Consequently, farmers seek informal in-kind loans from input suppliers (feed, PLs, chemicals) or informal monetary loans—sometimes at prohibitive interest rates (12% for the duration of the crop: 3 to 5 months). This type of access to financial capital induces them to choose lower quality inputs and to seek quick, high returns to cover their debts.

#### 3.1.4 Market knowledge and export requirements

Stakeholders identified market knowledge, market regulation, and market requirement problems. First, regarding market knowledge, farmers face issues regarding market access costs. Small-scale farmers cannot sell directly to processing companies or wholesalers because of their low production volume (under 100 kg per harvest in the case of extensive farmers) and do not have direct access to information on current market prices offered by processing factories. Each factory sets the buying price according to its demand, which can differ from the official market price broadcast in the media, and specific connections with processing factories are required to access this "real" price. This type of problem arises from a lack of interactions between small-scale farmers and processing companies, as well as from current informal contracts between traders and small-scale producers.

A second constraint concerns market price fluctuation. Farmers and other stakeholders are aware that farm-gate prices are dependent on other countries' production, currency exchange values, and demand on the US, EU, Japanese, or Chinese markets. For example, between 2015 and 2016, the *Penaeus monodon* (grade 25–30 pcs) price increased by 44%, from 250,000 VND/kg to 360,000 VND/kg, within a 10–15-day period (http://www.seafood.vasep.com.vn/; accessed September 2016). Farmers indicate that such price fluctuation increases the uncertainty of their profit and limits their investment. Underlying problems relate to the absence of institutions to partially regulate the market price, the absence of market mechanisms to reduce market risk for farmers, and a lack of interaction and knowledge infrastructure to exchange information and facilitate the integration of smallholders into the market.

A third constraint relates to export market requirements. This constraint derives from a lack of interactions and the absence of a knowledge infrastructure. In 2015, 38 countries returned 582 batches of Vietnamese aquaculture products (not only shrimp) due to antibiotic contamination. The inefficient control of antibiotic residues in the raw material leads to the banning of the exported seafood products, fines for the exporters, and reputational damage to exporters and processing companies, affecting the entire value chain. The underlying causes, besides access to banned products, are multiple. First, processing companies source 96% of the farmed shrimp from wholesalers (Tran et al. 2013) working with hundreds of small collectors and farmers. According to stakeholders, this structure limits not only the traceability of products and practices, but also the exchange of knowledge and information about new regulations and standards, as there is no proper knowledge infrastructure. Stakeholders also indicate a weak control system at processor and exporter level, with only a small sample of every shipment tested and untrustworthy results. Although certification of aquaculture is promoted in Vietnam, it is limited. Only 19 industrial farms were certified by the Aquaculture Stewardship Council in 2015. Benefits from certification are unclear for small-scale farmers. Certification is not always possible due to lack of infrastructure or land. It requires a large investment for producers, and benefits are limited, with no premium price (except for product certified as organic). The limited benefit in comparison to the investment required discourages farmers from seeking certification. In response to this constraint, the Vietnamese Government launched a national standard, VietGap, which is not yet recognized internationally, and local stakeholders are questioning this certification process, which does not include a third-party certification body.

Shrimp production systems are technically complex. They are changing fast, with frequent technological innovations promoted by the private sector not necessarily adapted to the Mekong Delta context and to farmers' perceptions and motivations. Our analysis shows that collaboration and interactions between actors in the sector are not performing adequately. The absence of a knowledge infrastructure and inadequate hard and soft institutions do not support interactions between value chain stakeholders to achieve market requirements and better market knowledge and access for smallholders.

## 3.2 Discussion of blocking mechanisms of interlinked constraints for sustainable intensification in shrimp aquaculture in Vietnam

From our findings, we identify three clusters of constraints that form blocking mechanisms (Fig. 3): (a) inadequate regulatory frameworks to control inputs and practices, (b) limited financial return and access to credit keeping farmers in unsustainable practices, and (c) productivity- and intensification-oriented policies supported by linear technology transfer. We explain how each blocking mechanism is constituted and reflect on what would be needed to relieve each of the identified blocking mechanisms.

### 3.2.1 Blocking mechanism 1: institutional and regulatory framework enforcement problems

A first blocking mechanism starts with the weak implementation of the regulatory framework to control input quality, making a wide range of low-quality or even banned products accessible to farmers. Limited enforcement of regulatory frameworks on wastewater and disease management contributes to the degradation of the local environment and reinforces farmers' belief in using additional inputs in the pond. Recent studies (Boyd and Engle 2017; Engle et al. 2017) also identify the diversity of inputs and their overuse by Vietnamese shrimp farmers as a cause of shrimp farm economic inefficiency. The vibrant market for aquaculture inputs in Vietnam is difficult to control, with both imported and locally produced inputs, and several ministries involved in quality control with overlapping responsibilities and unsatisfactory coordination between those entities. Inefficient and often unsustainable practices are partially caused by farmers' limited knowledge regarding pond ecology and by farmers receiving productivity-oriented training from the extension service and the private sector, reinforcing their belief in additional inputs to control disease or increase productivity.

This first blocking mechanism relates to several interlinked categories of structural elements that affect the functioning of the innovation system, such as hard institutions (i.e., lack of enforcement of regulatory frameworks on input quality and uses, lack of controls of water discharge in canals) and weak interactions between ministries, leading to a limited enforcement of the regulatory framework. In addition, the lack of a knowledge infrastructure (i.e., absence of platforms to facilitate interaction between ministries, lack of laboratories to control diseases) supports the continuation of malpractices, a constraint that relates to soft institutions (i.e., a belief in input-oriented solutions that supports high use of antibiotics).

Policies oriented toward intensification, and limited political will to regulate better the input market, support this causal loop and constrain the capacity to change toward sustainable practices. To interrupt this loop, changes are required in various structural elements of the innovation system, such as a political will to invest in reforming both the regulatory framework and the responsibilities of institutions in charge of controlling input quality and farmers' (mal)practices. This solution will require capacity building within government agencies (or other third-party certifiers) to apply this framework. In addition, infrastructure needs to be created to promote dialog between actors in the sector to improve product quality along the segments of the value chain and to be able to respond to international market quality requirements.

### 3.2.2 Blocking mechanism 2: limited financial return and access to credit maintaining a minimum investment attitude among farmers

A second blocking mechanism, linked to the first, concerns limited access to financial capital. This lack of financial capital pushes farmers to choose less expensive inputs, often of mediocre quality, thus increasing the chance of limited productivity and diseases outbreaks, while contributing to economic inefficiency. As a feedback loop, frequent disease outbreaks restrict access to loans from banks, which are now asking farmers to develop proper proposals and proof of past success before they

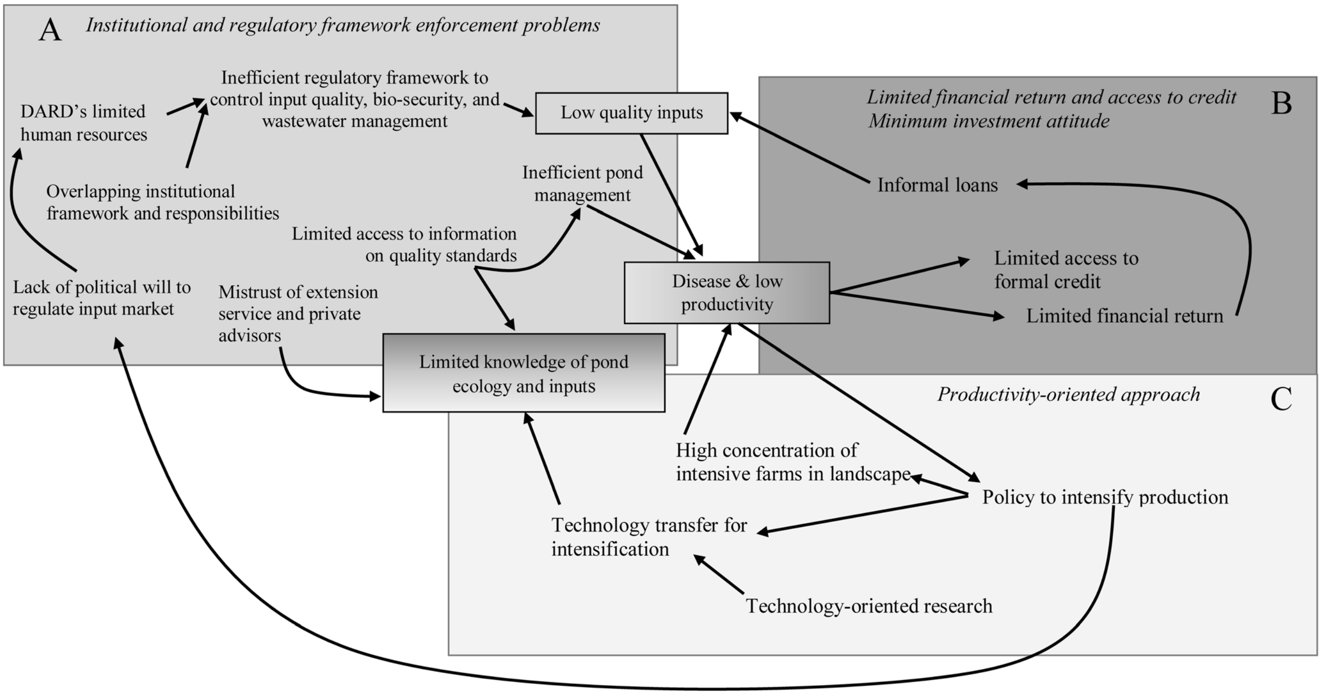


**Fig. 3** Connections among constraints that hinder sustainable intensification in shrimp farming in the Mekong Delta, Vietnam. **a**, **b**, and **c** Represent the three blocking mechanisms that hinder sustainable intensification. Arrows represent connections between constraints within the blocking mechanisms and connections between the three blocking mechanisms

will authorize loans. Farmers resort to informal loans, with high interest rates requiring quick returns to repay their loans, thus influencing technological choices toward low-quality and cheaper inputs. The core cause of this blocking mechanism thus lies in a lack of hard institutions facilitating access to capital for shrimp farmers. Access to credit for small-scale farmers could be reformed to encourage sustainable practices and discourage access to informal loans and the associated pond management practices. Promoting practices based on pond ecology, limiting the use of unnecessary inputs, can reduce operational production costs, which increase sharply when inefficient inputs are used (Boyd and Engle 2017).

### 3.2.3 Blocking mechanism 3: a productivity-oriented approach to shrimp farming at pond level

A third blocking mechanism concerns limited training on pond ecology principles to improve farmers' management capacities, linked to an intensification policy illustrated by increasing production targets. There is limited training on input use (such as minerals, pre-mix, and other additives) to build farmers' confidence in evaluating new products on the market, but the paradigm whereby technical solutions can resolve sustainability issues in shrimp aquaculture is still strong in the discourse of extension services and government policies in Vietnam. A related aspect of intensification policy is that current private and public sector extension services, supported by national research, promote intensification of shrimp production systems relying heavily (or solely) on external inputs for feed and on farm biosecurity measures (e.g., fencing, pond disinfection) to control the interaction of the pond system with the wider ecosystem. Shrimp ponds are connected to the ecosystem through waterways, and this means that ponds can easily be affected by water pollution and diseases. In the Mekong Delta context, with its multitude of smallholders concentrated in a monoculture landscape resulting from inadequate land-use planning, disconnecting ponds from the local ecosystem and applying strict biosecurity measures is unrealistic according to extension services and farmers. This last blocking mechanism relates to multiple problems with structural elements of the innovation system. Current pond management practices and productivity are directly related to soft and hard institutions supporting input-oriented solutions to ecological problems. In addition, there is a lack of physical infrastructures, or rather ecological infrastructures are not scaled to the density of shrimp farms in the coastal landscape, to enhance an adequate and ecologically sound (as opposed to ecologically unsound) connectivity between culture areas and the wider ecosystem.

To mitigate this blocking mechanism, a paradigm shift will be required in how shrimp aquaculture is promoted in the Mekong Delta in Vietnam. A greater emphasis must be placed on the pond ecology principle to conduct shrimp farming and create a pond ecosystem resilient to disease, where the disease vector can be present in the pond but outbreaks are not triggered (Hoa et al. 2011). Acknowledging the connectivity of ponds to, and their dependence on, the wider ecosystem will enable a landscape approach to better control disease outbreaks and improve wastewater management (Bush et al. 2010). This will require adequate investment in infrastructure and in the capacity of extension services to enforce the regulations necessary for a landscape approach to aquaculture.

## 4 Conclusion

Research on aquaculture innovation covers a wide array of approaches (Joffre et al. 2017). Although it has been shown to be useful to perform a holistic and integrated analysis, the use of an aquaculture innovation systems approach has been limited. Farm-level analysis is both the usual level of analysis in aquaculture and the proposed intervention level to achieve sustainable intensification (Engle et al. 2017). However, a main theoretical implication of our study is that it is essential to look at different levels (farm, value chain, policy environment) and dimensions in aquaculture systems and value chains using an aquaculture innovation systems approach.

Our analysis is the first aquaculture innovation system analysis, going beyond only technical or economic dimensions, in order to better inform interventions to support a transition toward the sustainable intensification of aquaculture. Our analysis applied mainly similar constraint categories (physical and knowledge infrastructure constraints, institutional and interaction constraints, and market structure constraints) as applied to sectors such as agriculture. In addition however, we have shown that the biophysical dimension and the ecological infrastructure need to be explicitly recognized, as most aquaculture systems are linked to, and dependent on, the wider ecosystem. This addition of an ecological dimension to the analytical framework echoes an earlier call advocating that socio-ecological perspectives be added to innovation system analysis (Joffre et al. 2017; Pigford et al. 2018).

The main policy implication of our analysis of constraints in the aquaculture innovation system hindering sustainable intensification in shrimp farming in Vietnam is that sustainable intensification requires several interventions beyond the farm level. The connectivity of the shrimp production system to the wider ecosystem needs to be taken into consideration when the aim is to achieve sustainable intensification in shrimp farming by supporting a landscape approach to it. In addition, a better spatial organization of farms is needed to improve water and disease control management and limit the concentration of intensive farms in the area without proper infrastructures. To address the identified blocking mechanisms, multi-stakeholder dialog needs to be promoted in relation to four principal areas. Firstly, it is necessary to respond to technical issues at pond level and support a system-wide paradigm shift in the way shrimp are raised by small-scale farmers. Secondly, dialog between the actors in the sector must be strengthened to respond to quality issues. Thirdly, policy must be steered toward supporting a landscape approach to aquaculture. Fourthly, the roles and responsibilities of the various agencies involved in controlling and regulating the sector and value chain must be defined. Multi-stakeholder dialog in terms of joint agenda setting and participatory innovation (see Dentoni and Klerkx 2015) is not common in a centralized government such as that of Vietnam (Minh et al. 2010). Therefore, initiating such dialog will require not only adaptation to the local institutional context and a gradual introduction of institutional innovation, but also a behavioral change by the actors in the sector toward more information exchange and collaboration.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.



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