Climate change adaptation in coastal shrimp aquaculture: a case from northwestern Sri Lanka

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ABSTRACT

Unexpected temperature variations and rainfall patterns have direct, adverse impacts on shrimp farmers in northwestern Sri Lanka. Specifically, changing climatic conditions impact patterns of shrimp disease spread along an interconnected lagoon and make it difficult for shrimp farmers to predict and control the lagoon—the primary water source for coastal shrimp aquaculture. This paper examines how small-scale shrimp farmers adapt to the impacts of climate change by collectively managing shrimp disease. We studied three shrimp farming communities in northwestern Sri Lanka and analysed adaptation using a social-ecological resilience approach with a four-part framework: (1) living with uncertainty — shrimp farmers deal with the uncertain nature of the shrimp business by controlling (rather than trying to eliminate) disease; (2) nurturing diversity — farmers tend to diversify their income sources to include other activities and they also increase the risk of disease by dispersing pond waste water in space and time; (3) employing different kinds of knowledge — farmers combine their experience with large-scale (failed) companies, their own experience, government technical expertise, and new knowledge from adaptive management (the "zonal crop calendar system"); and (4) creating opportunities for self-organization — farmers have built on their experiences with producer cooperatives, known as *samithi*, to self-organize into a multi-level community-based management structure. Collaboration and collective action are central features of this adaptation mechanism. This small-scale shrimp aquaculture system is persistent, i.e. sustainable and resilient because it is continually adapting.

INTRODUCTION

The aim of this paper is to examine how small-scale shrimp farmers adapt to the impacts of climate change by collectively managing shrimp diseases. The paper argues that building resilience can be one viable option for climate change adaptation and specifically answers two questions: (1) How do small-scale shrimp farmers adapt to the impacts of climate change by collectively managing shrimp diseases? (2) What are the sources of resilience?

We studied three small-scale shrimp farming communities in the northwestern region of the Democratic Socialist Republic of Sri Lanka. All coastal aquaculture in the northwestern region produces black tiger shrimp (*Penaeus monodon*). The Democratic Socialist Republic of Sri Lanka is a small-scale shrimp producer in terms of quantity, but this case study provides unique insights into adaptation and resource management.

Large-scale shrimp farming survived in the country only from the late 1970s to the mid-1990s. However, small-scale shrimp farming has persisted since the early 1990s. It is important to know therefore if shrimp aquaculture in the hands of small-scale producers can be made more resilient and thus more adaptable to climate change.

Most literature about shrimp aquaculture concentrates on the wide range of adverse social and environmental implications (Belton, 2016; Benessaiah and Sengupta, 2014). The impacts of large-scale shrimp aquaculture are unpredictable and inequitable (Galappaththi and Berkes, 2014), depending on the level of vulnerability of social-ecological systems (Bush *et al.*, 2010). Few scientific studies illustrate how to engage in sustainable shrimp aquaculture (De Silva and Davy, 2010).

Recent literature on the country's shrimp aquaculture reflects diverse perspectives. For instance, Harkes *et al.* (2015) identified shrimp aquaculture as a vehicle for climate-compatible development, suggesting how the sector can support the mitigation of greenhouse gas emissions and adaptation to climate change impacts while stimulating rural development, aligning with the previous government's (Mahinda Chinthana) development plan. Bournazel *et al.*, (2015) described the impacts of shrimp farming, focusing on land use and carbon storage around Puttlam Lagoon. Galappaththi and Berkes (2013) examined the northwestern shrimp aquaculture using a social-ecological systems approach, focusing on the surviving small-scale shrimp farmers and how they deal creatively with uncertainties and complexities in natural resources management. Small-scale shrimp aquaculture operations have maintained close relationships with the environment on which, along with natural resources, they depend for their livelihoods and well-being. Interestingly, government statistics show incremental improvement in aquaculture shrimp production since 2005. Almost all national shrimp aquaculture production comes from tiger shrimp farming in the northwestern region (Figure 1).

FIGURE 1
Total aquaculture shrimp production (tonnes)

Source: NAQDA (2017).

This paper analyses adaptation to climate change among small-scale shrimp farmers in northwestern region of the Democratic Socialist Republic of Sri Lanka. A social-ecological resilience approach with a four-part framework is used. The approach emphasizes neither the ecosystem alone nor the social system alone but rather the interconnected social-ecological system as the unit of study (Berkes *et al.*, 2003). Resilience is "the ability of a system to absorb or rebound from disturbance without shifting to another fundamentally different system configuration" (Armitage *et al.*, 2007: 330). Social-ecological resilience is a key aspect related to the building of adaptive capacity (Berkes *et al.*, 2003). The framework we use identifies four ways to build social-ecological resilience to adapt to environment and climate change: (1) living with change and uncertainty; (2) nurturing diversity; (3) fostering learning; and (4) combining different kinds of knowledge (Folke *et al.*, 2003). Adaptation is the act of making something fit a new situation or use (Adger *et al.*, 2009). The literature highlights the importance of the cultural dimensions of climate adaptation (Adger *et al.*, 2013), and private sector engagement (Tompkins and Eakin, 2012).

METHODS

The study was undertaken using a qualitative case study approach (Hancock and Algozzine, 2015). Mixed data collection methods were used to capture the wide range of representative data on different local climate-adaptation and resilience-building efforts (Berg, 2016). First, participant observation was conducted in three shrimp farming communities in the northwestern region to obtain a contextual understanding of shrimp farming operations and climate adaptation. The data collection was carried out from 2012 to 2013; it involved spending time in shrimp farming communities and actively engaging in daily shrimp farming operations such as post-larvae stocking, water quality monitoring, shrimp harvesting, and attending producer cooperative meetings.

Second, semi-structured interview data were collected from 38 shrimp farmers using snowball sampling to obtain diverse and detailed qualitative data about collective action (Ostrom, 1990) undertaken with respect to climate adaptation, such as a zonal crop calendar system, the use of different kinds of knowledge for building climate resilience, and the role of producer cooperatives. Third, three focus group discussions were organized with shrimp farmers and government officers in each community to understand the overall shrimp aquaculture governance structure and to learn how information flows from the local to the national level for decision-making. Focus group meetings were used to clarify and validate other data collected though participant observation and interviews.

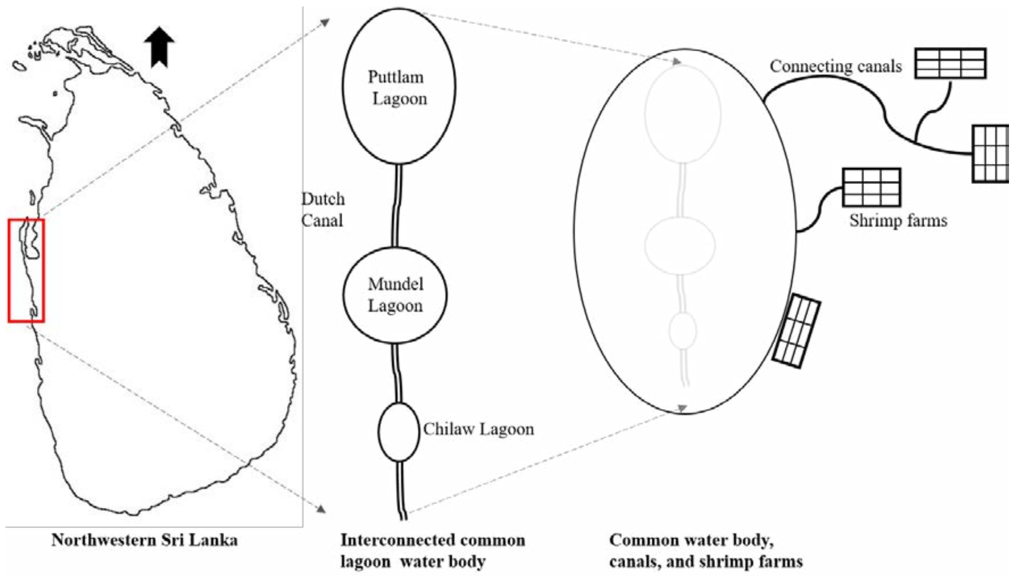
Fourth, seven key informant interviews were conducted with relevant government officers, feed suppliers, hatchery owners, members of shrimp processing companies, and other reputable and experienced people in the sector, including the shrimp farmers who introduced the present zonal crop calendar system. Finally, 28 unplanned on-the-spot interviews were conducted during national-level and zonal-level meetings. Analysis of the data began after the labeling and coding of each piece of subscribed data. Content analysis was supplemented with mind maps and management processes were used to create themes and bring meaning to the findings. This research was conducted in accordance with the Canadian ethical guidelines for research and the research protocols of the University of Manitoba, Canada.

The study area is in the coastal belt of the northwestern province of the country. Shrimp farming is the dominant industry in this area because of the specific soil characteristics and the brackish water required for black tiger shrimp aquaculture (Galappaththi and Berkes, 2015a). The brackish water is found in three lagoons—Chilaw, Mundel, and Puttlam. Coconut plantations and mangrove areas are among the most common types of vegetation found in the northwestern coastal belt. Income-generating activities related to shrimp aquaculture include shrimp broodstock collecting, hatcheries, shrimp farming, middlemen shrimp harvest collectors, shrimp processing and export companies, feed suppliers, and laboratory services (Galappaththi *et al.*, 2016).

In terms of the profile of shrimp farmers, most of them (42 percent) were between the ages of 40 and 50 years old. The youngest group consisted of three farmers (8 percent) under 30 years old. Shrimp aquaculture experience within a community ranged from 2 to 15 years, with a majority (66 percent) having more than 10 years of experience. The majority (37 percent) had some level of high school education, whereas 26 percent graduated from high school. Most (72 percent) shrimp farming operations were family-based, involving family labour and the wife, son, daughter, and other relatives, who contributed labour, kept the books, managed the farm, and engaged in producer cooperative activities. Almost all recorded shrimp farms were owner-operated. In terms of the scale of the operations, the size range of the pond area (pond size) varied from 0.2 hectares to 0.8 hectares. In 2012-2013, the majority (37 percent) of farmers operated two to five ponds. Some experienced shrimp farmers recalled that the large-scale shrimp operations in the 1990s were about 150 hectares in size (Galappaththi, 2013).

Climate change impacts northwestern shrimp aquaculture in the form of droughts, unusual monsoon patterns and floods, and unexpected temperature fluctuations (De Silva *et al.*, 2007). Climate impacts vary depending on the shrimp farming area. The southern part of the northwestern coastal region (Chilaw Lagoon) is characterized by relatively wet (raining and flooding) climatic conditions, with lagoon water salinity varying mostly by single digits. Unusual salinity drops in the Chilaw Lagoon system can increase the incidence of shrimp diseases. The northern part of the coastal belt is dominated by dry (drought) conditions, and water salinity in Puttlam Lagoon remains high (up to about 70 percent), creating unfavourable conditions for shrimp growth. Adequate rainfall between crop seasons helps flush out sediments from tanks that contain mud and debris, which could lead to poor water quality. Inadequate rain leaves shrimp farmers more susceptible to shrimp disease. Furthermore, unexpected extreme weather events such as flooding (e.g. the May 2016 floods) can damage elements of shrimp farming infrastructure, such as ponds and canals.

FIGURE 4
Sketch of the ponds and the canal/common water body where water is discharged/drawn



RESULTS

Shrimp aquaculture operations started in the late 1970s with four multi-national companies (Liver Brothers', Enris, Carson, and Andrew's) that initiated large-scale operations in an integrated fashion (Galappaththi and Berkes, 2014). Local people who worked in large companies learned shrimp farming techniques and later started small-sized and medium-sized shrimp farming upon the failure of the large companies in the face of challenges mainly related to shrimp disease (mainly white spot syndrome).

Shrimp disease is the primary adverse effect of the impacts of climate change on shrimp aquaculture in the northwestern region. The industry suffered a series of shrimp disease outbreaks (in 1989, 1996, and 1998) with significant damage to the sector. Presently, almost all northwestern shrimp farmers are small-scale farmers. These shrimp farmers together identified the key issue of the industry—shrimp disease spread by the interconnected lagoons (Figure 2). This body of water consists of mainly three lagoons and connects to the canal (called the Dutch Canal) running from the Colombo Kalani river mouth to the Puttalam Lagoon. Almost all the shrimp farmers rely on this interconnected lagoon for withdrawing and discharging used pond water. Shrimp farmers identified patterns of the spread of shrimp disease through the Dutch Canal, which varies with annual weather events and patterns. Once shrimp farms discharge disease-infected water into the common body of water, it starts spreading all over the water flow. The dynamics of the spread of disease depend on weather patterns such as monsoon rain.

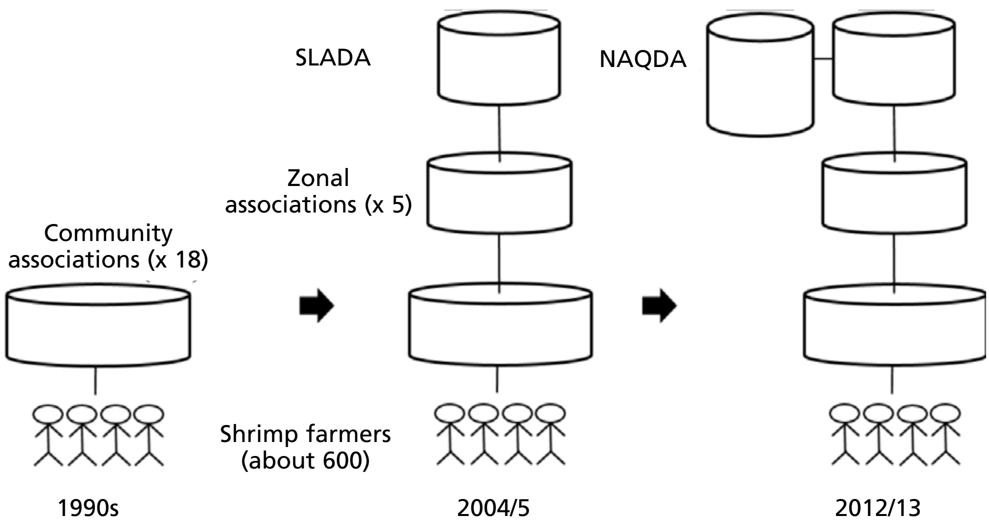
The key solution, thus, is to manage discharge and withdrawal dates from the common body of water. This serves to control (but not eradicate) shrimp disease. However, the solution requires collective action, action undertaken together by all shrimp producers connected to the lagoon to achieve a common (rather than individual) objective. Shrimp farmers achieved collective action through their community association (producer cooperative), collaborating with other producer cooperatives. This system is known as the "zonal crop calendar system" (ZCCS). ZCCS was introduced by shrimp farmers with the support of the National Aquaculture Development Authority of Sri Lanka (NAQDA) and private-sector shrimp farming stakeholders such as feed suppliers, hatcheries, processing companies, and consultancy servicers (all together called the Sri Lanka Aquaculture Development Association (SLADA) —the sector association for the shrimp industry).

How does ZCCS work? Shrimp farmers divide the northwestern shrimp farming area into five zones, with each zone divided into several sub-zones (equivalent to shrimp farming communities). Initially, these zones were created after a study of the spreading patterns of shrimp disease over the past years. Shrimp farmers, SLADA, and NAQDA collaboratively decided which zone (or sub-zone) can (or cannot) support farming during a particular crop season (three crops per year). This crop calendar is finalized after a series of meetings, which tend to involve many debates and arguments; individual and community-level power dynamics play a visible role in these debates. ZCCS became an annual process because of the ongoing but unpredictable impacts of climate change, such as unusual monsoon patterns and floods, and unexpected temperature fluctuations. As shrimp farmers are not farming in all three crop seasons, most farmers (85 percent) can diversify into other income-generating activities, such as fishing, vegetable farming, shrimp feed selling, and coconut farming. ZCCS is judged to be working well, both by farmers and government officials According to one NAQDA officer:

> *Before introduction of ZCCS, white spot [disease] spread aggressively in large areas and result[ed in] huge losses to many shrimp farms. But, now, with the implementation of ZCCS farmers are not getting such losses. We know [we still] have white spot disease in our lagoons and we are still getting diseases [in] certain parts of the lagoon, but we have minimize[d] the risk of losing [the] shrimp harvest because of [the] low occurrence of shrimp disease.*

ZCCS is managed by the multi-level institutional structure (Galappaththi and Berkes, 2014) that has evolved over time. Shrimp farmers have had community-level associations since the 1990s. Some of them were registered under the Sri Lankan cooperatives act and some were registered under relevant divisional secretariat officers. With the problems related to shrimp disease, farmers organized and formed the national-sector association SLADA. Development of ZCCS led to the creation of five zonal shrimp farmers' associations to represent multiple community associations. To strengthen the implementation of ZCCS, SLADA asked that the Ministry of Fisheries engage a government institute as a facilitator and monitor of the system. Since 2004-2005, SLADA and NAQDA have collaboratively worked for ZCCS implementation. Annual zonal crop calendar meetings start at the community level, eliciting shrimp farmers' feedback about previous crops and thoughts about coming crops. This feedback is forwarded to the SLADA-NAQDA decision-making body through zonal institutions (Galappaththi and Berkes, 2015b). All levels (from shrimp farmer community to the national level) are represented in the final meeting and decisions are made collaboratively.

FIGURE 5
Adapting institutions and structures



Multi-level adapting institutions drive the ZCCS. Presently, maintaining membership in the producer cooperatives is obligatory for carrying out shrimp farming in the northwestern area. This creates a mechanism for networking and access to the right information, such as good shrimp feed brands, shrimp market prices, selling experience with processing companies, and disease active areas. The producer cooperative helps community farmers work collectively and share their knowledge related to shrimp aquaculture. For example, during a shrimp harvesting event, cooperative members get together to help their fellow members. Some cooperatives provide compensation to farmers who have diseased ponds (depending on the average size of the shrimp at the harvest). The cooperative is the place where farmers share their farming techniques during monthly meetings. Moreover, cooperatives send their member farmers to government-sponsored technical workshops and to other relevant knowledge-gathering meetings in the region.

Some shrimp farmers have an understanding of the importance of lunar cycles and mangrove vegetation for the shrimp farming environment, and they use that knowledge to foster better shrimp farming techniques. For example, some farmers do not harvest on full-moon nights. Water pumping of the ponds is done only at a certain time of day, taking into account the tides and currents. Certain farmers in the region seem to be less vulnerable to shrimp disease. These shrimp farms are covered by dense mangrove vegetation. Field observations found that the inlet water of these farms is filtered through millions of mangrove roots. These farmers rely on the same raw material sources (post-larvae, feed), as do other farmers who continue to be highly vulnerable to shrimp diseases.

DISCUSSION

Sri Lankan coastal shrimp aquaculture shows the results of efforts to build resilience and adapt to the impacts of climate change. Collaboratively managing the ZCCS for disease control is the key to building resilience. The ZCCS seems to work because: 1) ZCCS is developed and introduced by the shrimp farmers themselves with the support of government institutions (Galappaththi and Berkes, 2015b); 2) the multi-level and bottom-up institutional structure of ZCCS facilitates the crop calendar development process (Galappaththi and Berkes, 2014); 3) shrimp farmers, the government, and the private sector are cooperatively involved in decision-making in ZCCS (Tompkins and Eakin, 2012), 4) ZCCS is an adaptive process evolving annually (Galappaththi and Berkes, 2015b); and 5) collective action and collaboration are the heart of the ZCCS mechanism (Galappaththi and Berkes, 2015a). We discuss the adaptation of Sri Lankan shrimp farmers using a social-ecological resilience approach with a four-part framework.

First, shrimp farmers learn to live with change and uncertainty by managing shrimp diseases (and their outcomes) rather than trying to eliminate the diseases (Berkes *et al.*, 2003). Large-scale companies left the aquaculture industry upon the outbreaks of shrimp disease because they could not survive in the midst of the changes and uncertainties created by the disease. However, small-scale shrimp farmers in the northwestern region collectively faced the challenges of the disease by adopting an annual zonal crop calendar based on the memory of past events, such as shrimp diseases and weather pattern changes (Folke *et al.*, 2003).

Second, shrimp farmers use diversification strategies for climate adaptation. They manage disease risk by controlling the release of used pond water in space and time (Galappaththi and Berkes, 2015b). Before the introduction of ZCCS, the lagoon water system was used by shrimp farmers throughout the year to withdraw and discharge pond water (Galappaththi and Berkes, 2014). At such times, shrimp disease can spread over the lagoon faster than at present and create large losses for most of the farmers connected to the lagoon via water (disease conditions can remain present for a long period of time). Because ZCCS limits boundaries in space and time, the spread of disease is restricted to smaller geographical areas, and losses for farmers are relatively smaller and more recoverable. By taking turns at using lagoon water, shrimp farmers spread the risk of disease. In addition, limited crops per year allow shrimp farmers to engage with other sources of income and not be limited to shrimp aquaculture.

Third, shrimp farmers use different kinds of knowledge (Table 1). Farmers combine their experiences with large-scale (failed) companies, their own experiences

TABLE 1
Types of knowledge adopted by shrimp farmers

Type of knowledge	Description
Shrimp production techniques	Current small-scale shrimp farmers learned shrimp farming techniques from pioneering multinational companies during the late 1970s and 1980s. This knowledge continues to evolve from generation to generation.
Marketing knowledge	Community associations provide required updated information related to shrimp marketing, selling prices and buyers, feed brands and prices.
Local environmental knowledge	This includes how to use mangroves to minimize shrimp disease risk, when water should be pumped into the ponds, and harvesting with consideration of the lunar cycle (to minimize the risk of shrimp disease).
Knowledge and practice with respect to collective action	Sri Lanka has a tradition of collective action. Shrimp farmers apply this knowledge to face their challenges, creating cooperatives, associations, and other groups to work efficiently.
Co-produced knowledge	By working together and sharing and learning from each other, and working together with SLADA and NAQDA, shrimp farmers combine and co-produce new knowledge.

as farmers, and government-sponsored technical workshops on shrimp production. Shrimp farmers' local knowledge about mangroves and lunar cycles indicates their close relationship to nature and natural resources (Galappaththi, 2013); they apply this knowledge to their day to day shrimp aquaculture operations, but the actual effectiveness of this knowledge has not been studied or explained. Furthermore, Sri Lankan shrimp farmers maintain local and traditional knowledge about collective action. The country has a history of collective action, especially in the fisher cooperatives in the coastal fisheries sector. Shrimp farmers' associations include informed members who have up to date marketing information. Community institutions play a significant role in helping shrimp farmers share and co-produce knowledge.

Fourth, Sri Lankan shrimp aquaculture cases show how to foster learning while living with the challenge of disease. Farmers have built on their experiences with producers' cooperatives to self-organize into a multi-level community-based management structure. This structure allows shrimp farmers to learn at multiple levels of governance (community, zonal, and national levels). The ZCCS is revised yearly. Every year, shrimp farmers learn from their ZCCS and bring those lessons to formulate the next year's crop calendar. Producers' cooperatives play a large role in bringing these lessons to the national level. The system uses feedback and operates on the basis of "learning by doing" (Folke *et al.*, 2003).

These four sources of resilience from small-scale farmers can be recognized as different but interrelated ways to adapt to the impacts of climate change in shrimp aquaculture. However, we are not arguing that the shrimp aquaculture governance in the Democratic Socialist Republic of Sri Lanka is perfect in terms of equitable distribution of benefits among farmers, as power imbalances inherent throughout the process can affect the resilience of social-ecological systems. However, the overall effectiveness of the ZCCS and the methods of resilience building in this aquaculture system are reflected in the sustainability and gradual increase in aquaculture shrimp production as shown in Figure 1 earlier.

How does climate change impact shrimp aquaculture governance in the northwestern region? ZCCS is the prime mechanism to build resilience for facing the challenge of shrimp disease. Crop calendar planning is based on the prevailing shrimp disease in the lagoon, whereas weather predictions rely on past weather experiences. From a social-ecological resilience perspective, unexpected and extreme weather increases the uncertainty and complexities of northwestern shrimp aquaculture social-ecological systems. Furthermore, shrimp farmers modify and adapt best management practices introduced by the NAQDA at the community level as appropriate for the local environment. Unexpected changes in climate limit the effectiveness of these "better management practices." However, shrimp farmers trying to manage the complexities and uncertainties created by climate change use an adaptive management (learning by doing) approach to implement ZCCS (Armitage *et al.*, 2007). Implementation of ZCCS is supported by the sources of resilience identified above using a four-part framework (Folke *et al.*, 2003).

CONCLUSIONS AND FUTURE DIRECTIONS

In conclusion, shrimp disease spreading along the lagoon is the key challenge for Sri Lankan coastal shrimp farmers. Shrimp farmers have self-organized with government support, implementing a calendar system to manage shrimp disease impacts. Climate change impacts, such as unexpected weather and extreme events, increase the complexities and uncertainties of shrimp disease control. Resilient small-scale shrimp aquaculture hinges on the collective action of individual owners through producers' cooperatives and collaborative multi-level management. Sources of resilience recognized in the Sri Lankan shrimp farming case include living with change and uncertainty, nurturing diversity, using different kinds of knowledge, and fostering learning, consistent with Folke *et al.*, (2003). Small-scale shrimp aquaculture persists (it is sustainable) because it is resilient and adaptive.

This paper shows that sources of resilience, collaboration among stakeholders, and collective action are the key features of adaptation. This study advances the knowledge necessary to address issues that have theoretical significance for resource management, and practical significance for sustainable aquaculture. The original research project produced publications regarding institutions for managing aquaculture commons (Galappaththi and Berkes, 2014), applications of commons theory to shrimp aquaculture (Galappaththi and Berkes, 2015a), co-management (Galappaththi and Berkes, 2015b), and information sharing through community cooperatives and its impact on shrimp supply chain management (Galappaththi *et al.*, 2016). The present study provides insights for sources of adaptive capacity to deal with climate change. Given current discussions about adaptation, climate change adaptation in Sri Lankan coastal shrimp aquaculture deserves further attention.

A better understanding of possible ways to adapt to climate change in shrimp aquaculture requires theoretical and practical attention to expand the knowledge base. Concepts of climate change adaptation and resilience require more attention to apply to small-scale aquaculture settings in better ways. Only a limited number of studies are available on resilience and climate adaptation in shrimp aquaculture. To understand climate change adaptations and sources of resilience, regional-level (South Asia, Southeast Asia) projects are needed to provide case studies for comparative analysis. Finally, a substantial part of the world's aquaculture production is coming from small-scale producers. Thus, it is important to discover how community-based institutions can carry out shrimp aquaculture as an alternative to large-scale commercial aquaculture. This is not to suggest that large-scale shrimp production operations could be completely replaced by community-based aquaculture. Rather, it is a potential approach to build climate-adaptable, resilient aquaculture systems in the future.

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