Impacts of climate change on aquaculture in Vietnam: A review of local knowledge

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Traditional sea cage.

The aquaculture industry in Vietnam plays an important role in both food production and employment. Vietnam is the 4th largest aquaculture producer in the world after China, India, and Indonesia and in 2016 contributed 4.5% of the world's total production[1]. The majority of Vietnam's aquaculture production occurs at the small, or familial scale. Of the 2.4 million households that are involved in aquaculture, 75% of them have farms that are less than 2 ha in area and 90% are less than 3 ha[2]. The small-scale nature of Vietnam's aquaculture sector makes it particularly vulnerable to the unpredictable and changing weather patterns brought on by climate change.

According to Germanwatch's Global Climate Risk Index, Vietnam is in the top ten countries most affected by climate change. In 2017 they were ranked 6th in the world[3]. This ranking is based on combined socio-economic and extreme weather event data spanning over a 20-year period. The index value indicates a country's level of vulnerability and exposure to extreme events[3,4]. A combination of geographic and social factors makes Vietnam especially vulnerable to climate change. Vietnam has a vast coastline which exposes it to typhoons and flooding. Additionally, 20% of Vietnam's total area falls within a low elevation coastal zone, a coastal area with an elevation of 10m or less. 55% of the country's population live within these areas[5]. As sea levels rise, low lying areas will become increasingly affected by flooding and saltwater intrusion. Vietnam's socio-economic situation also make it particularly vulnerable to climate change impacts. Vietnam is a quickly developing country, but there are still many low-income areas. Low-income earners will be most impacted by climate change as they do not have the monetary resources available to adapt.

Farmers are at the frontlines of experiencing climate change as their livelihoods are intrinsically linked with the natural environment. Weather patterns and external natural inputs are all important factors in the success of their crops. Therefore, they observe and monitor environmental trends closely so that they can adjust their practices when necessary.

Aquaculture farmers in Vietnam are especially vulnerable to change. Sea cage farms are located offshore where they are exposed to storms, while shrimp farms are often located in low lying areas that are impacted by rising sea levels.

Aquaculture farmers are experiencing the impacts of climate change firsthand. Therefore, our study aims to collect and summarise local knowledge of aquaculture farmers living in South Central Vietnam. We visited sea cage, hatchery, and shrimp farms throughout Khanh Hoa and surrounding provinces to interview farmers and aquaculture experts. We also had the opportunity to meet with several shrimp farmers from the Mekong delta. The purpose of the interviews was to gather firsthand knowledge on current climate change impacts experienced by farmers, as well as which climate change threats they are most concerned about, and how they are adapting to these threats. We hope that the experiences and knowledge of aquaculture farmers presented in this paper can be used by other farmers who are seeking strategies to similar climate impacts, and for aquaculture researchers to better understand the current threats facing farmers.

Major climate change threats

The biggest climate change threats identified by interviewed farmers are an increased intensity of storms, warming temperatures, and reduced weather predictability. These threats are already impacting farmers and their effects are only expected to worsen.

Storms

An increasing intensity of storms was a concern shared by all interviewed farmers. Farmers have noticed that in recent years storms are causing more and more damage to their facilities resulting in higher repair costs. Storms are damaging farm infrastructure such as roofs, pond walls, and cages. They also cause power outages which impact a farmer's ability to oxygenate the water and can lead to fish/shrimp mortality. Typhoons are a particularly frightening threat for farmers as they are unpredictable, result in major damages, and there is very little that can be done to protect against them.

In 2017, Vietnam was affected by the typhoon Damrey which hit the Khanh Hoa province the hardest resulting in hundreds of millions of dollars in damage. Khanh Hoa is the province where most interviewed farmers live. Every shrimp and hatchery farmer interviewed reported extensive damage to their farms while all sea cage farms in the area were entirely wiped out by this typhoon. Prior to 2017, the area had not experienced a typhoon in over a decade. Farmers had grown accustomed to not having to check the weather or worry about major storms. Since 2017, farmers watch the weather carefully and most have some form of a plan in place for future typhoons and major storms.

Sea cage farms are the most vulnerable to typhoons since their offshore location leaves them unprotected from storms. A typhoon will destroy a sea cage farm's infrastructure. Therefore, the typhoon plans put in place by farmers are focused on salvaging stock rather than protecting infrastructure. Several interviewed farmers said that they have in land aquaculture

Feeding cobia.

Shrimp nursery.

ponds where they can move their brood stock to in the case of major storms. Others opt to harvest their stocks early. Some farmers have decided to transition from the traditional wood/bamboo sea cage structure to the Scandinavian style plastic cages that can better withstand storms. The cost differential however is massive with the traditional cage set up costing around US$50,000 and a plastic cage costing around a million. One sea cage farmer, Mr. Hung, pointed out that a plastic sea cage is still likely to be severely damaged in a storm by the debris from neighbouring wooden cages.

Warming temperatures

For farmers, the biggest impact of warming temperatures on aquaculture production is the increased prevalence of disease. The interviewed farmers all expressed concern over the increasing disease rates in their stocks and they contributed it to the warming and changing environment. Every living species has a tolerance range for abiotic environmental conditions. This means that there is a maximum and a minimum temperature that each fish or shrimp species can tolerate. With warming temperatures, many aquaculture species are living at, or near the maximum end of their range. This creates stress and makes them more susceptible to disease. Mr. Vinh, a hatchery owner, said that he has noticed a significant reduction in cobia (*Rachycentron canadum*) survival. 5 years ago, if cobia reached 2 kg their survival was almost 100%. Now he is finding mortality in cobia that are larger than 2 kg. He has also found that pompanos have become harder to cultivate as they are becoming increasingly sensitive to disease.

Living in stressful environmental conditions can also reduce an organism's ability to reproduce successfully. Farmers are worried that in the future they may no longer be able to farm some staple native species. For example, Mr Hung said that some species can only breed in the winter when the water temperature drops below 23 degrees. With the cold season becoming shorter, the water may eventually be too warm for these species to fertilise successfully.

Reduced predictability of weather

Climate change is resulting not only in warmer temperatures in Vietnam but is also causing shifts in weather patterns. Farmers are observing the impacts of reduced weather stability in many ways. Droughts and heavy rain periods have become harder to predict. They are occurring during abnormal times of the year and with greater intensity. Shrimp farmers are finding that this is making it more difficult to maintain good water quality. Large rainfalls reduce their ponds salinity while drought increases it. Mr Hung, a farmer with sea cages said that large rain events are also impacting his operations. His cages are located in a closed bay, so the inland run off into the bay reduces salinity levels and delivers inland pollutants to the sea.

Many farmers have also noticed a shift in the seasons. They say that over the past few years the divide between the wet and dry season is becoming less distinct. Weather patterns that used to only occur during the dry season are now happening during the wet season and vice versa. Farmers have observed that the wet season is becoming shorter. This

Table 1. Summary of impacts to aquaculture farmers resulting from climate change threats.

System	Increased storm intensities	Increased temperatures and temperature anomalies	Rainfall anomalies and droughts	Rising water levels
Hatcheries	Damage to infrastructure Electricity outages. Reduced demand from customers.	Increased disease occurrence.	Flooding.	Flooding.
Sea cages	Damaged infrastructure, especially vulnerable to typhoons. Lost fish stocks from ripped nets.	Increased fish mortality Reduced spawning and fertilisation success. Increased prevalence and reduced predictability of disease.	Increased rainfall resulting in inland pollutant transfer and reduced salinity.	Increased inland pollutant transfer.
Shrimp farms	Damage to infrastructure. Electricity outages stopping pumps and water oxygenation equipment. Increased rainfall reducing the salinity of ponds.	Increased prevalence and reduced predictability of disease. Reduced ability to maintain consistent pond temp and salinity levels.	Large rainfalls reduce the salinity of shrimp ponds. Droughts reduce ability to maintain consistent salinity levels.	Flooding results in damaged infrastructure and escaped stock. Increased soil salinisation from infiltration.

Table 2. Summary of climate change adaptation strategies applied by aquaculture farmers.

System	Increased typhoon frequency and severity	Inconsistent and rising temperatures	Unpredictable weather patterns / seasons	Increased disease and mortality
Hatcheries	Stronger roofs / sandbagging roofs. Backup generator stored up high.	Reduce stocking densities.	Monitor weather and water quality. Reduce stocking densities.	Reduce stocking densities. Manage feeding to reduce feed pollution. Apply permitted antibiotics.
Sea cages	Monitor weather. Move brood stock to an inland pond facility.	Move cages to open ocean. Increase depth of cages.	Monitor weather closely. Change to more tolerant species. Shift farming season.	Wash nets with fresh water often. Reduce stocking densities. Harvest early. Change to more tolerant or faster growing species. Apply permitted antibiotics.
Shrimp farms	Monitor weather. Sand bag roofs. Cover ponds. Harvest early.	Rear juvenile shrimp in covered ponds. Shift to indoor ponds.	Closely monitor water quality. Shift farming season.	Apply Biofloc systems. Transition to a multi-trophic polyculture system. Apply natural prophylactic remedies. Use high quality seed. Apply permitted antibiotics.

is particularly problematic for farmers practicing integrated rice-shrimp farming as the wet season is becoming too short for many rice varieties.

Another major impact of unpredictable weather is that diseases are becoming less predictable. A common trend between interviews was that farmers are finding it increasingly difficult to manage for disease. Farmers are finding that diseases that used to only occur during specific seasons or at certain points in an organism's lifecycle are now occurring year-round and during all life cycle stages. Mr Vo, a Mekong shrimp farmer, has noticed that early mortality syndrome (EMS) has become much less predictable. Within the last three years he has found EMS to occur year-round and during all shrimp life stages, before EMS had specific and expected periods where it was a problem.

Adaptation strategies

Farmers are already implementing adaptation strategies for current climate change impacts as well as devising future strategies. These strategies are based on government recommendations, information acquired at local training sessions, knowledge from university educations, and personal experience.

Infrastructural adaptations

Farmers are making structural changes to adapt to climate change impacts. They are finding that building deeper ponds and sea cages is an effective way to protect against warmer temperatures and to mediate temperature swings. Farmers with more monetary resources are considering shifting their

farming practices indoors to protect against unpredictable weather. This however is not a feasible option for smaller scale farmers. Most of the shrimp farmers interviewed said that they have started using covered nurseries to help shrimp adapt to the warmer temperatures. Juvenile shrimp spend their first 25 days in a covered pond where they are protected from the heat. This gives them a chance to gain strength before they are moved to the exposed ponds. One problem that farmers are finding with this method is that the shrimp juveniles reared in these covered nurseries have softer shells then those reared in uncovered ponds.

Mixed farming methods

A transition to mixed farming methods could help farmers adapt to climate change impacts by reducing their reliance on external water inputs and diversifying their income. Systems such as biofloc and integrated rice-shrimp farming are already widely applied by farmers in Vietnam while multi-trophic polycultures such as algae-shrimp or tilapia-shrimp polycultures are still uncommon[6]. These systems rely on natural nutrient cycling to recycle aquaculture waste products. They allow farmers to recycle the water in their systems, reducing the risk of bringing in disease and pollutants from external sources. Farming multiple species provides a backup source of income to farmers. If one crop fails, they still have another crop to sell.

Mr Dung, an engineering specialist at a medium scale shrimp farm, explained to us the biofloc system his farm implemented in 2010. They combine the biofloc mixture with water and molasses to grow the bacteria. This mixture is then added to the shrimp ponds where the bacteria consume the waste produced by the shrimp. Along with the biofloc bacteria mixture, Mr Dung adds natural prophylactic ingredients to help prevent gastrointestinal diseases. He adds a combination of fermented green banana, garlic, and ha chau plant (*Phyllanthus urinaria*) to the ponds. He estimates that since the farm implemented the biofloc system, shrimp survival rates have increased from 50% to between 70-90%.

Multitrophic aquaculture systems are mixed farming methods based on natural nutrient and waste cycling between trophic levels. In an algae-shrimp polyculture, wastewater from the shrimp ponds is cycled through ponds containing algae. The algae consume the waste produced by the shrimp which purifies the water. This water can then be cycled back into the shrimp ponds. Species from additional trophic levels can be added to create a more complex polyculture. For example, tilapia can be added to filter feed organic waste materials and will provide an alternate income source for the farmer[6].

Integrated rice-shrimp systems are common in the Mekong region. Shrimp are farmed during the dry season and rice is grown during the wet season. This method of mixed farming provides a year-round source of income. Mr Vo, a shrimp farmer in the Mekong delta, has been practicing integrated rice shrimp farming for twelve years. He believes that maintaining an integrated system is crucial for farm health especially with climate change. In his experience, a successful rice crop will mean a healthy shrimp crop. Recently however, maintaining this system has become more difficult for him. There has been an increased intrusion of saltwater from sea level rise and flooding that is causing the soil to become more saline. He has also noticed that the wet season is becoming shorter. This has forced him to change his practices to farm

Above, below: Growing biofloc.

short season rice species. He is concerned that as weather patterns continue to change, he may run out of ways to adapt to climate change.

Collaboration

As climate change threats worsen, collaboration and collective action between farmers in Vietnam's aquaculture industry will become increasingly important. Many of the threats facing farmers extend past the farm and sectoral level and are impacting aquaculture farmers in multiple regions and across sectors. Working as a collective to share information and devise strategies for managing common threats will be key in protecting livelihoods. Collaboration gives farmers the opportunity to learn which techniques are working well or are not working well for fellow farmers and how they can apply successful techniques to their own farms. Current collaboration efforts are organised formally through government

Hatchery produced pompano seed.

created farmer's associations, while our interviews tell us that farmers are also choosing to collaborate informally with their neighbours and colleagues.

Our interviews show polarisation between the willingness of farmers to collaborate. Some farmers were entirely opposed to collaboration because they consider other farmers to be their competitors while others said that they are already sharing ideas and techniques between farms. All farmers interviewed however agreed that government organised information sessions are a useful way for them to learn about new technology and adaptation strategies.

Conclusions and recommendations

The information gathered during the interview process demonstrates that across multiple areas of aquaculture, farmers are aware of the changes occurring, contribute them to climate change, and are applying adaptation strategies. This was true for farmers from all educational backgrounds. We also found a high level of consensus between farmers as to what the biggest threats they face are and which adaptation strategies they are applying. Farmers agreed that the increasing intensity of storms along with the increasingly unpredictable weather are having the biggest impacts on their farming practices. Farmers across various sectors said that they are monitoring the weather much more closely, reducing their stocking densities, and building deeper ponds or cages to adapt to changing temperatures.

As a result of climate change, farmers are faced with higher management costs and increased risk. When making adaptation decisions they must consider the trade off between money and risk. For example, some farmers are choosing to harvest their crops early to reduce the risk of losing their crops to disease or storms. By doing this they are accepting a lower income as the fish or shrimp will be smaller, but they are eliminating the chance that they lose everything. A similar trade off situation exists with hatchery production. Rising temperatures are resulting in increased disease occurrence. In order to prevent disease outbreaks, hatchery farmers are reducing their stocking densities. Lower stocking densities means less profit, but also a reduced chance of losing a stock to disease.

Vietnam's aquaculture industry, especially small-scale producers, relies heavily on external environmental inputs and weather patterns. This forces farmers to be aware of environmental changes as they can have major impacts on their livelihoods. Farmers are at the forefront of experiencing and reacting to change. Therefore, gathering the experiential knowledge of farmers is important when developing new climate change adaptation strategies. Successful plans will require open communication between government, farmers,

and researchers in order to develop plans that are both feasible and meet the current needs of farmers. We also recommend that future adaptation plans focus on the needs of small-scale aquaculture producers since they are the majority and the most vulnerable to climate change impacts.

This study demonstrates that aquaculture farmers in Vietnam have a breadth of valuable climate change knowledge. They have first-hand experience with current climate change threats impacting their industry and insight into successful adaptation strategies. As one of the top ten countries most impacted by climate change, the threats facing Vietnam's aquaculture industry will likely worsen. This will severely impact the industries ability to produce enough fish and seafood to feed demands and impact farmer's abilities to make a living. The experiential knowledge of farmers is an important tool that should not be undervalued when making decision about how the industry can adapt to climate change.

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Water quality monitoring test kits.