investigation on the genetic improvement program for this mollusk species group, particularly in Viet Nam (Vu *et al*., 2020). On the other hand, Malaysia evaluated the aquaculture potential of inter- and intra-specific crosses between *C. belcheri* and *C. iredalei* (Wan Nawang *et al*., 2019).

Way Forward

The rapid growth of aquaculture production in the region requires a sufficient supply of seedstocks, especially marine seeds, given the expansion or shift towards mariculture. Sustainable seed production can be achieved through genetics-based breeding programs to ensure the selection and maintenance of genetically variable breeders through successive generations capable of producing seedstocks that are healthy, fast-growing, and resilient to diseases and environmental stresses. Breeding programs are strongly practiced among freshwater species, particularly tilapia, which allowed the development of various strains with superior growth performance. For marine crustaceans, particularly penaeid shrimps, significant threats from viral diseases have forced similar breeding programs to ensure the availability of disease-free spawners and seeds. Such breeding programs are uncommon in the marine fish industry given major issues that persist in captive breeding. Research and development activities are underway to circumvent the reproductive difficulties surrounding marine fishes although technologies take considerable time to be established. The consolidated progress of genetics, fish health management, intensified culture system, and cost-efficient feed program can lead the way in creating a more sustainable aquaculture production in the succeeding decades. Non-technical intervention from the government is needed to address the gap. The centralized breeding facility for marine fish to supply backyard hatcheries proved efficient in enabling mass seed production. Enabling policies and incentives should be promoted to encourage more operators to venture into the production of seedstocks.

7.1.5 Production of Safe and Quality Aquaculture Products

As the human population continues to grow, coming with it is the greater demand for food. Aquaculture is the fastest-growing food source, and the industry tries to catch up with demands through rapid intensification. However, this intensification has resulted in the occurrence of diseases and degradation of the environment. Farmers have resorted to using antibiotics as therapeutants to prevent and treat diseases. Chemicals and products that have claimed to improve water and soil quality or strengthen the immune system of shrimp and fish had been introduced into the market. Also, fish farmers have been using different kinds of feed (live and manufactured), which could be contaminated with harmful chemicals and zoonotic organisms. Moreover, the indiscriminate use of antibiotics could result in antimicrobial-resistant strains of bacteria. These antimicrobial-resistant genes can be transferred horizontally from aquatic to terrestrial to human and vice versa, affecting the organisms and the environment. Some countries are stricter to the point that detection of drug residues in imported aquaculture products means rejection. Consequently, the production of safe and quality aquaculture products is a challenge to fish farmers, and the current trend is towards responsible aquaculture through ecosystem approaches for the production of safe and quality aquaculture products.

Safe and quality aquaculture products

Recognizing the threat that antimicrobial resistance (AMR) brings, the Food and Agriculture Organization of the United Nations (FAO) implemented a project on the prudent and responsible use of antimicrobials in fisheries and aquaculture in 2017. The project was aimed at developing and enhancing the knowledge, skills, and capacity of the participating Competent Authorities (CAs) on fisheries and aquaculture; and assisting the CAs to develop and implement policies and national action plans (NAPs) on the prudent and responsible use of antimicrobials.

Recognizing the importance of detection protocols for different food hazards, the SEAFDEC/MFRD and the SEAFDEC/AQD with funding from the Government of Japan, developed standardized methods of their detection. Laboratory manuals on the detection of antibiotic and pesticide residues were published including oxolinic acid and oxytetracycline/tetracycline/chlortetracycline by high power liquid chromatography (HPLC)-fluorescence method in 2004; 29 pesticides residue using gas chromatography in 2004; and chloramphenicol and nitrofurans using liquid chromatography-tandem mass spectrometry (LC-MS/MS) method in 2005. SEAFDEC/MFRD also produced three Technical Compilations, namely: 1) Heavy Metals, Pesticide Residues, Histamine and Drug Residues in Fish and Fish Products in Southeast Asia 2004-2008; 2) Biotoxins Monitoring in ASEAN Region 2009-2012; and 3) Traceability Systems for Aquaculture Product in the ASEAN Region 2010-2015. Moreover, two regional guidelines were developed by SEAFDEC/MFRD, namely: 1) Traceability System for Aquaculture Products in the Asian Region and 2) Cold Chain Management of Fish and Fishery Products in the ASEAN Region. Aside from manuals on antibiotic and pesticide residue detection, SEAFDEC/AQD also published a manual on antimicrobial sensitivity tests including bacterial isolation and identification techniques in 2004. SEAFDEC/AQD acquired an atomic absorption spectrophotometer for the detection of heavy metals and metallic elements. Detection of different foodborne pathogens using polymerase chain reaction (PCR)-based methods were also reported such as *Escherichia coli* (2008), *Salmonella* spp. (2008), *Shigella* spp. (2010), *Staphylococcus aureus* (2010), and *V. Cholerae*

(2010). Detection protocols or kits for other food hazards, such as histamine, have also been made available.

To assist the exporting countries in designing and implementing food safety guidelines and protocols that comply with the European Union (EU) requirements, the EU organized the Regional Workshop on Safety of Aquaculture Products in 2018. Attended by the representatives from the AMSs and lecturers from Europe, the Workshop included lectures, hands-on training, case studies, and discussions geared toward bringing participants in a position where they could identify the gaps and non-compliances in their national systems, thus, contributing to improved and reinforced sanitary and phytosanitary frameworks necessary in the respective AMSs.

In order to obtain updates on the current aquaculture practices in the region, SEAFDEC/AQD organized the International Workshop on the Promotion of Sustainable Aquaculture, Aquatic Animal Health, and Resource Enhancement in Southeast Asia (SARSEA) in 2019. With funding from the Government of Japan, the Workshop was attended by representatives from the AMSs reporting on the status of their respective practices on sustainable aquaculture, aquatic animal health, and resource enhancement, including pressing issues, gaps, possible strategies, and recommendations. The country paper presentations were followed by a workshop that identified problems and issues in realizing sustainable aquaculture. Some of the issues focused on food safety, traceability of aquaculture products, non-compliance to good aquaculture practices (GAqP), ecolabelling, and environmental degradation.

To address the environmental and food safety issues arising from aquaculture practices, several research and verification studies related to the production of safe and quality aquaculture products that maintain the integrity of the environment have been carried out by SEAFDEC/AQD. Studies on responsible aquaculture through ecosystem approach are on mangroves to purify farm effluents, greenwater culture system, integrated multi-trophic aquaculture (IMTA), and biofloc technology (BFT). Other studies are on the implementation of biosecurity measures. Lectures on GAqP, food safety, and biosecurity measures have been incorporated into the training courses offered by SEAFDEC/AQD.

Good Aquaculture Practices

GAqP is a series of considerations, procedures, and protocols designed to foster efficient and responsible aquaculture production and expansion, to help ensure final product quality and safety, as well as environmental, economic, and social sustainability. GAqP implies the

Table 74. Steps in aquaculture production relevant to GAqP and Food Safety that farmers generally practice

Steps	Practices
Site selection	Sites that are near residential areas (presence of human wastes, chemicals), near other farms, both agricultural (presence of runoffs, pesticides, fertilizers, manures) and aquaculture (due to contaminated water; disease transmission), near industrial establishments (presence of heavy metal contamination, PCBs), and near forest reserves are avoided, while water sources are checked to make sure that these are free from contaminants or food hazards
Pond design and construction	Ponds are designed to have separate water inlets and outlets, and are provided with a reservoir to stock water before use in ponds; and settling ponds to receive pond effluents before draining water to the sea; while some shrimp farms incorporate shrimp toilets in their ponds
Pond preparation	Pond preparation involves a series of activities that provide a contaminant-free environment to the organism to be cultured, making it safe for human consumption, and some of these activities include: • *Sludge removal*. Sludge is removed as this could contain toxic substances, high organic load, and microorganisms that contaminate the cultured organisms • *Plowing or tilling*. Plowing or tilling helps in the breakdown/oxidation of organic residues and other toxic substances that the cultured organisms may assimilate • *Liming*. Liming is carried out to kill any biological food hazards
Seed stock	Seed stocks are obtained from areas not contaminated with any food hazards
Water management	Water coming in and out of the culture pond is filtered and treated
Feeding	Feeds and feed ingredients are free from unsafe levels of biological, chemical, and physical contaminants and/or other adulterated substances, while all ingredients used must be free from prohibited substances
Grow out culture or production technique	The use of drugs is avoided, and in cases where drugs are used, the recommended withdrawal period is observed to avoid detection of drug residues in the aquaculture products, while the culture environment adapted to the species raised is maintained at all phases of production, and specifically: • Stock and environmental conditions are routinely monitored for early detection of aquatic animal health problems • Management practices implemented are those that reduce the likelihood of disease transmission within and between aquaculture facilities and natural aquatic fauna, and reduce stress on animals for the purpose of optimizing health
Harvest and post-harvest	Make sure that fish are free of antibiotics and other residues before these are harvested, while the harvested products are immediately washed and iced to avoid accelerating the spoilage process

production of safe aquaculture products for human consumption that also addresses environmental, economic, and social sustainability for on-farm processes, resulting in safe and quality food and non-food agricultural products. Steps in aquaculture production are important factors in delivering safe aquaculture products to the consumers and environmental sustainability. Some of these factors relevant to producing a safe and quality aquaculture product generally practiced by farmers in Southeast Asia are presented in **Table 74**.

Furthermore, in order to yield safe and quality aquaculture production, efforts toward the development of novel technologies, the introduction of innovations, and the establishment of systems continue. For example, aquaculture mimicry or aquamimicry is a concept where natural estuarine conditions are simulated in culture ponds. This is facilitated by establishing zooplankton blooms, mainly copepods, and beneficial bacterial populations to improve and maintain water quality. The plankton serves as supplemental feed to the cultured organisms. Aquamimicry has been used for shrimp farming in Brunei Darussalam, Indonesia, Malaysia, Singapore, and Thailand.

Aquaponics combines traditional aquaculture (fish, prawns) with hydroponics (cultivating plants in water) in a symbiotic environment. Effluents from aquaculture are filtered out by the plants as vital nutrients, after which the cleansed water is re-circulated back to the ponds. Aquaponics is practiced by most Southeast Asian countries such as Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Viet Nam.

Biofloc technology or BFT uses aggregates microbial communities of bacteria, algae, or protozoa, and living or dead particulate organic matters, and involves the manipulation of carbon to nitrogen (C:N) ratio to convert toxic nitrogenous wastes into useful microbial protein that serves as food to fish while water quality is improved. A carbon source is usually added to the culture water, such as cassava, rice bran, and molasses. BFT helps improve water quality under a zero-water exchange system, thus preventing the introduction of diseases to fish farms from incoming water. Although the use of the BFT is quite expensive considering that it requires a high-density polyethylene (HPDE) liner to line the pond bottom and rigid aeration at all times, it is being adopted to culture fish and shrimp in Brunei Darussalam, Indonesia, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Viet Nam.

The greenwater culture system is a technique that cultures an aquatic organism in water abundant in phytoplankton, *e.g.*, chlorella, turning the water green. Greenwater culture provides highly nutritious culture water that serves as feed for the fish and shrimp stock. In shrimp culture, greenwater is usually produced from growing tilapia, where reservoirs are stocked with high saline tilapia or other finfish such as siganids. After > 14 days, the water from the reservoir with finfish can be used to culture shrimp. Greenwater is practiced in Malaysia, the Philippines, and Viet Nam.

Integrated multi-trophic aquaculture or IMTA is the farming in the proximity of species from different trophic levels and with complementary ecosystem functions in a way that allows one species' uneaten feed and wastes, nutrients, and by-products to be recaptured and converted into fertilizer, feed, and energy for the other cultured commodities. The by-products including wastes of one aquatic species, serve as inputs (fertilizers or food) for another. In the IMTA, the cultivation of fed species is combined, such as finfish or shrimp, with extractive species, such as shellfish and seaweeds. IMTA is not new in the Philippines and is now gaining popularity in Indonesia, Malaysia, and Viet Nam. In Thailand, IMTA is combined with the Recirculating Aquaculture System (RAS).

RAS is another approach for removing major toxic pollutants from the culture water without causing environmental concerns. Pond effluent passes through a series of filtration systems to remove solid wastes, ammonia, microbes, and oxygenated before flowing back to the culture ponds. In Brunei Darussalam, its hatchery for giant freshwater prawns and mangrove crabs makes use of the RAS technology. Sea bass, hybrid groupers, red snapper, and saltwater tilapia had also been cultured following the RAS starting in January 2021, as well as in its grow-out farms for giant freshwater prawns. Meanwhile, a white leg shrimp farm in Cambodia which started operating in 2019, uses a super-intensive indoor RAS. In the same year, a RAS farm for the cultivation of *Pangasius* opened in Indonesia and in early 2016, a RAS farm for catfish cultivation started operation. Usually, RAS is being adopted in Indonesia to revive the dwindling eel industry. RAS has been practiced in Malaysian finfish hatcheries, while in Singapore, RAS is used in both hatcheries and farms. In the Philippines and Viet Nam, RAS is being used to culture tilapia in hatcheries and farms. The use of RAS in culturing mangrove crab became popular in the Philippines in recent years, and Thailand uses the RAS system to farm shrimp.

Hazard analysis critical control point (HACCP) is a system for managing and documenting processes to assure food safety. A HACCP system is designed to identify the significant hazards associated with the products or operations and establish procedures to monitor the products and operations to ensure that hazards are controlled. Previously, HACCP is the responsibility of food processors and not of producers of raw food materials. At present, HACCP principles have been used to assess different risks in aquaculture in Cambodia, Lao PDR, the Philippines, Thailand, and Viet Nam.

Importing countries have set standards with regards to the safety of exported aquaculture products, checking for antibiotic residues and the presence of other contaminants or food hazards. They are also particular with the method and the environment of the products that were produced, and whether the farmers practice responsible aquaculture to ensure environmental sustainability. To address these issues and ensure that farms adhere to these standards, exported aquaculture products need to obtain certification from recognized certification bodies. Several aquaculture certification services assist farmers in Southeast Asia to demonstrate responsibility and adherence to best practices. Some of these include the Aquaculture Stewardship Council (ASC) which is supported by the World Wildlife Fund (WWF) issues certification for aquaculture products that target the American and European markets; Best Aquaculture Practices (BAP) which is developed by the Global Aquaculture Alliance (GAA) and is used by the American markets; and GlobalGAP that is used for products targeting the European markets. Indonesia, Malaysia, the Philippines, Thailand, and Viet Nam are some of the clients of such aquaculture certification bodies.

Issues, Challenges, and Constraints

Food safety of aquaculture products starts at the farm level. However, aquaculturists, especially small-scale farmers, have low awareness and understanding of food hazards and their effect on humans and the environment. In spite of the extensive effort of both the government and local and regional institutions to educate the aquaculture sector on food safety, food hazards, good aquaculture practices, HACCP, certification, antimicrobial resistance, among others, the majority of the stakeholders remain adamant, non-compliant to GAqP, still uses antibiotics, and rejects government advises. This leads to the production of aquaculture products that are unsafe for human consumption and the possible degradation of the environment. Adoption of GAqP by the aquaculture sector would require a great effort on the part of the governments.

Way Forward

Responsible aquaculture through ecosystem approaches for producing safe and quality aquaculture products is one direction to produce safe and quality aquaculture products. Practicing the principles of HACCP should be promoted and recommended to the aquaculture sector. Information, education, and communication strategies and techniques to create food safety awareness among the stakeholders should be improved so that even those who could not go to school would understand the importance of delivering safe aquaculture products. Government should assist, especially the small-scale farmers in the implementation of GAqP, not only in terms of technology but also financially.

7.1.6 Impacts of Intensification of Aquaculture on the Environment

For several decades, aquaculture has emerged as a significant contributor and the fastest-growing food sector in the world (FAO, 2020) bringing economic benefits to rural and coastal communities while playing an increasingly vital role in global food security (Beveridge *et al*., 2013; Bene *et al*., 2016). The benefits of aquaculture include simple access to high-quality food, a source of income, and revenue for developing countries (Martinez-Porchas & Martinez-Cordova, 2012; Salin & Ataguba, 2018). The aquaculture sector has continued to dominate in developing countries, particularly in Asia (de Silva & Davy, 2010); and contributed to an average of 90 percent of the total volume of aquaculture production globally (Hall *et al*., 2011), wherein 16 percent came from Southeast Asia in 2019 (**Figure 101**). In Southeast Asia, aquaculture rapidly expanded in response to market demand, both domestic and international (Hishamunda *et al*., 2009). The highest producing country from Southeast Asia is Indonesia followed by Viet Nam, accounting for an average of 62.10 percent and 17.41 percent, respectively, of the total volume of the region's production in 2019 (**Figure 102**).

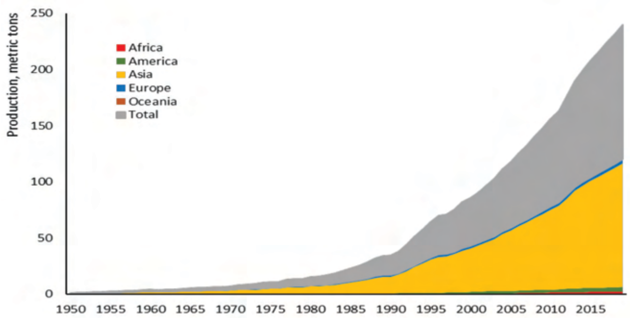

Figure 101. Total volume of aquaculture production from 1950 to 2019

*(**Source:** FAO Database)*

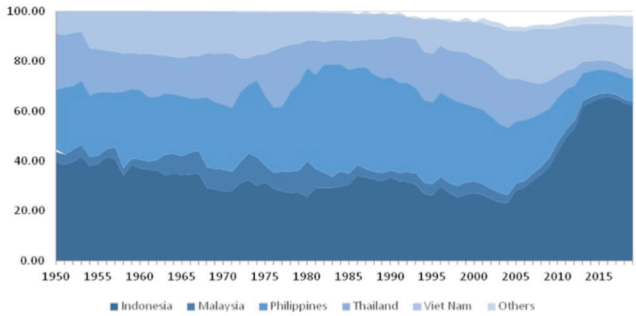

Figure 102. Percent contribution of Indonesia, Philippines, Malaysia, Thailand, Viet Nam, and other Southeast Asian countries (Brunei Darussalam, Cambodia, Lao PDR, Myanmar, Singapore, and Timor-Leste) to the total volume of aquaculture production in Southeast Asia from 1950 to 2019

*(**Source:** FAO Database)*