patterns of mariculture production. Results showed that socioeconomic conditions are a significant contributor to whether a country would engage in mariculture and the magnitude of its operations. The socioeconomic parameters, including governance factors, explained up to 33 % more of the variation in mariculture production compared to models including only biophysical parameters. Therefore, improving seafood farming infrastructure, creating local demand for seafood, and facilitating knowledge transfer from land-based and freshwater aquaculture could help countries develop stronger mariculture industries.

In Thailand, policy instruments are recommended to address the problems reportedly encountered by its aquaculture sub-sector that faces a range of production, market, and financial risks extending beyond the private space of farms to include public spaces and shared resources. The Government of Thailand has attempted to manage these shared risks using the lens of territorialization and institutionalized risk management through spatially explicit forms of collaboration among and between farmers and non-state actors in the shrimp and tilapia production sectors in the country (Sampantamit *et al*., 2010). Its findings demonstrate how these policy instruments address risks through dissimilar but overlapping territories that are selectively biased toward facilitating the individual management of production risks while enabling both the individual and collective management of market and financial risks.

7.1.2 Fish Health Management

Aquaculture is the fastest-growing food-producing sector in the world. In 2018, inland aquaculture accounted for 62.5 percent of the world's farmed food fish production. A 527 percent rise in global aquaculture production was observed from 1990 to 2018. However, this production growth is being threatened by fish diseases resulting in losses of more than USD 6 billion per year (FAO, 2020). In this regard, fish health management is one way of abating the problem, which begins with disease prevention and control rather than treatment. One component of fish health management is the emergency preparedness and response system (EPRS) for managing aquatic disease outbreaks. EPRS comprises contingency planning arrangements that can minimize the impacts of severe aquatic animal disease outbreaks through containment or eradication in case of disease occurrence. In 2016, the EPRS was harmonized among the AMSs with the initiative of SEAFDEC/AQD in collaboration with the Network of Aquaculture Centres in Asia-Pacific (NACA), Food and Agriculture Organization of the United Nations (FAO), ASEAN Network of Aquatic Animal Health Centres (ANAAHC), and Department of Fisheries, Thailand (DOF Thailand).

Disease surveillance and monitoring program

In different countries, disease surveillance or monitoring is one of the activities being conducted to determine the presence of diseases in their territory or to demonstrate disease-free status. Except for Cambodia and Lao PDR, most AMSs have a monitoring or surveillance program. Diseases included in the monitoring and surveillance program are usually those listed in the OIE database and other significant and emerging aquatic animal diseases. However, some AMSs have different priorities with respect to disease surveillance and monitoring. Like for example in Malaysia, surveillance is conducted on diseases that cause high economic losses for the country. In Brunei Darussalam, an active surveillance program is carried out in the shrimp industry and a passive surveillance program for the rest of the country's fish industry.

Quarterly, the AMSs submit the aquatic animal disease reports to the OIE and NACA through the OIE Regional Office in Tokyo, Japan and NACA headquarters in Bangkok, Thailand. In addition, the AMSs provide disease information on the OIE-listed aquatic animal diseases to the OIE World Animal Health Information System (WAHIS) every six months. Information in the WAHIS can be accessed and verified by the public.

Information on emerging diseases provided by the OIE, FAO, and NACA are communicated by competent authorities to the stakeholders to raise their awareness. Furthermore, precautionary measures are recommended such as movement restrictions, health certification, and quarantine to control the introduction or spread of the emerging transboundary diseases.

Fish health diagnostic laboratories

An important aspect of aquatic animal disease prevention and control is the existence of a laboratory with skilled personnel who conduct diagnostic services at different levels (**Box 32**). The fish health diagnostic laboratories of the respective AMSs (**Box 33**) are managed by personnel who continuously undergo training to update and enhance their skills in carrying out disease diagnoses.

Box 32. Disease diagnosis levels (Bondad *et al.*, 2001)	
Level I	Diagnosis is done through gross clinical observation: observation of the cultured animals and the environment
Level II	The laboratory is capable of traditional diagnostic techniques like bacteriology, mycology, parasitology, and histopathology
Level III	The laboratory is capable of advanced diagnostic techniques like virology, electron microscopy, molecular biology, and immunology

Box 33. Fish health diagnostic laboratories in the AMSs	
Brunei Darussalam	The Aquatic Animal Health Services Centre (AAHSC) of the country's DOF is responsible for providing diagnostic services to the growing aquaculture industry in the country, making use of the OIE standards in performing diagnostic tests on aquatic animals
Cambodia	The Marine Aquaculture Research and Development Center (MARDeC) is the laboratory for aquatic animal health diagnosis in the country, which can perform Levels I and II disease diagnosis, but not for all aquatic species and diseases
Indonesia	A total of 140 aquatic animal disease laboratories including 15 fish health and environment laboratories operate under the Directorate General of Aquaculture (DGA), 47 laboratories under the Fish Quarantine Inspection Agency (FQIA), three under the Research, Development and Extension Agency (RDEA), and 75 laboratories managed by the local government, while the private sectors in the provinces usually have fish health officers and in-house Level I and II laboratories, and those under the DGA are national reference laboratories capable of Level III diagnosis that is being operated by the local government and mostly Level I laboratories that focus on water quality monitoring
Malaysia	The four service laboratories under the Fisheries Biosecurity Division of the country's DOF and one National Fish Health Research Division laboratory are managed by the Fisheries Research Institute and can perform Levels II and III diagnoses
Myanmar	DOF of Myanmar is capable of Levels I and II disease diagnosis, while the country's Aquatic Animal Health and Disease Control Section (AAHDCS) is capable of Level III diagnosis
Philippines	The National Fisheries Laboratory Division (NFLD) under the Bureau of Fisheries and Aquatic Resources has a central fish health laboratory and 16 counterpart fisheries laboratories in the regions with different levels of diagnostic capabilities on the detection of diseases, and there are two more fish health diagnostics laboratories, one at SEAFDEC/AQD and the other under the Negros Prawn Producers Marketing Cooperative Incorporated, that are capable of Level III disease diagnosis
Thailand	DOF Thailand has two national reference laboratories for aquatic animal health operating under its Aquatic Animal Health Research and Development Division (AAHRDD) for freshwater aquatic animal disease diagnosis and the Songkhla Aquatic Animal Health Research Center (SAAHRC) for brackishwater aquatic animal disease diagnosis, and there are 19 regional laboratories under the DOF located in different areas of the country
Viet Nam	There are 41 aquatic disease diagnostic laboratories in the country that include eight aquatic animal disease testing laboratories under the Regional Animal Health Offices (RAHO) and the National Centre for Veterinary Diagnosis (NCVD), 27 laboratories under the provincial Sub-Department of Animal Health (Sub-DAH), and six ISO/EIC 17025 accredited laboratory under the National Agro-Forestry and Fisheries Quality Assurance Department (NAFIQAD), while there are also privately-operated laboratories at the Research Institute for Aquaculture and in a fisheries university, and some private laboratories that are also accredited to provide diagnostic services for aquatic diseases

To improve laboratory competency, some laboratories in Brunei Darussalam, Indonesia, Philippines, and Thailand participated in the proficiency testing program for aquatic animal diseases organized by the Australian Centre for International Agricultural Research (ACIAR) and NACA, the Asia-Pacific Laboratory Proficiency Testing Program by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Government; and the Australian National Quality Assurance Program (ANQAP) and Arizona University. Indonesia also availed of the twinning program with the OIE Reference Laboratory.

Early Response System

Fish farmers and extension officers in the respective AMSs are knowledgeable in recognizing disease emergencies based on their experience and shared information among farmers. Fish farmers are trained to recognize signs of OIE-, nationally-, locally- listed aquatic animal diseases, emerging diseases, or unexplained mortality at Level I diagnosis. Some farmers also attend local and international seminars and other meetings on aquaculture practices and fish health management. Compliance with the requirements for certification, registration, or accreditation of aquaculture farms also improves farmers' knowledge of aquatic animal diseases. In addition, information, education, and communication (IEC) materials such as posters, disease cards, leaflets, manuals, and other publications are distributed to frontline individuals at the pond from time to time.

In Brunei Darussalam, when a disease is detected, the farm is declared as an infected zone, and a disease action plan is enacted. Containment, mitigation, and eradication of the disease are immediately implemented. Routine monitoring of the farm is conducted until the area is declared safe and free from the disease.

Indonesia, Malaysia, and Singapore have task forces that respond to aquatic disease emergencies. The task force investigates the cause of mortality, provides guidance on the implementation of standard operating procedures for a massive fish kill, and assists in key decisions regarding fish disease treatment procedures. DOF Malaysia also conducts risk analysis to identify high-priority aquatic disease threats that might be introduced to the country. The Import Risk Analysis (IRA) covers a list of diseases, biodiversity, or genetic threat to national aquatic resources, which are included in the application for the importation process. All registered farms in Malaysia are obliged to notify the DOF in case of occurrence or suspicion of a listed fish disease or the occurrence of mass mortality. The country developed

a Fish Disease Notification Form that is distributed to registered farms.

In Indonesia, farmers and farmer associations are encouraged to report disease occurrence to the nearest fish health office immediately and to submit samples to the nearest fish health laboratory. Farmers can directly report fish mortality to the competent authority through a short text message or an online application, and indirectly, through an extension service or the nearest laboratory of the national fish diseases information system.

In Singapore, the Aquatic Animal Contingency Plans are activated when the notifiable aquatic disease is detected in a farm or other aquatic animal holding facilities. The key aspects of the contingency plans include quarantine and movement restrictions of affected animals, vaccination (for specific pathogens *e.g.*, RSIV), compliance to proper biosecurity measures, on-site investigation and sampling of susceptible fish species from the affected farm and adjacent farms, culling of affected and in-contact fish, disinfection and cleaning of the premises and all in-contact equipment and tanks, and re-inspection of the premises to ensure compliance with disinfection and biosecurity protocols.

Standard operating procedure

In Brunei Darussalam, when imported fish are detected positive for diseases, the competent authority of the exporting country is notified to investigate traceability. The disease action plan is immediately implemented to prevent disease spread in the country. Once a report on fish disease or mortality is received in farms, the Mobile Technical Unit (MTU) of DOF is immediately sent to the site to investigate. The infected pond is immediately quarantined, and the information gathered with the samples collected will be sent to AAHSC for confirmation. In case of a confirmed disease incidence, the disease action plan is implemented.

In Cambodia, the officers of the Fisheries Administration Cantonment of each province contact and report any disease occurrences to the aquatic animal health officers at the national level (Fisheries Administration). The suspected or diseased aquatic animal samples are collected and sent for further diagnosis.

In Indonesia, the fish farmer reports suspected disease occurrence to the extension officer and laboratory personnel at the district level, either personally or through an internet-based system or application. Through the latter mechanism, farmers can directly report to CA through SMS gateway, phone, and website. The system has positive results but needs improvement.

In Viet Nam, in case of disease occurrence in the farm, the farm owner must notify the CAs at communal or district levels, then the information will be transferred to the provincial level (Sub-DAH), and the DAH (headquarters and regional office). After receipt, the information is verified, and once the case of disease occurrence was verified, the provincial Sub-DAH conducts a field investigation to assess the situation and take samples for pathogen identification. When the causative agent is identified, an updated report is submitted to the DAH and RAHO. The DAH supervises the implementation of the provincial Sub-DAH and guides and supports in case of new or dangerous disease outbreaks. The Sub-DAH reports aquatic disease situations to the MARD and international organizations, co-operates, and requests their help in emergency disease occurrence. The collaborating agencies include D-FISH, the national extension system, Research Institutes and Universities, and farmers' associations.

The other AMSs like Myanmar, Malaysia, Philippines, Singapore, and Thailand, report the result of their respective Monitoring and Surveillance Program as an SOP for the early detection of disease occurrence or outbreaks.

Awareness building and training programs

The competent authorities annually allocate budget for training programs for their own staff and farmers. The training program aims to update new regulations, enhance knowledge and skills in recognizing clinical signs of incoming diseases, and the prevention and control protocols for specific aquatic animal diseases.

DOF Brunei Darussalam annually conducts training courses and on-the-ground awareness building for farmers and fisheries staff from the MTU and AAHSC on recognizing signs of the listed diseases, emerging diseases, or unexplained mortality. Pamphlets and posters on diseases related to the farmer's cultured commodities are distributed to help recognize any signs of diseases in their farms. To build national expertise on aquatic animal diseases, concerned staff are required to attend training courses on laboratory diagnostics every year.

Cambodia has established and enforced laws on reporting aquatic diseases. This action is supported by an equally aggressive campaign to raise awareness of the aquatic animal disease and health management. Competent officers, farmers, and even the public undergo several training and attend workshops at the central and provincial levels as part of the information dissemination and awareness programs. Additionally, the aquatic animal disease and health management officers produce manuals on fish health and disease management. Meanwhile, aquatic animal farmers are encouraged to adopt good aquaculture practices (GAqP).

Indonesia recognizes that public awareness of fish disease outbreaks is fundamental, particularly among farmers and stakeholders. They must understand how to prevent outbreaks, treat them, and eradicate diseases so that they can

independently minimize mortalities, economic losses, and spread of disease to other ponds or farms. Public awareness is improved through national seminars and workshops, public counseling, and the distribution of brochures and leaflets in central aquaculture production in the Indonesian region.

In the Philippines, fisheries health officers are required to undergo training conducted by the NFLD on fish health management before assuming their designations. The NFLD staff act as resource persons in in-house training sessions as well as in workshops, fora, and formal training courses conducted by the regional offices and other government and non-government organizations. Training programs for staff development and capacity building are included in annual plans. Training courses on fish health management are also being offered by SEAFDEC/AQD. Fish health experts in the Philippines are often invited to join and collaborate for regional projects of the FAO, NACA, OIE, EU-TRTA, and other organizations on aquatic animal health.

For Thailand, the DOF regularly updates its websites where staff, farmers, industry stakeholders, and others get information on the disease status and events within or out of the country. AAHRDD and SAAHRC update publications and produce new ones annually. In case of severe disease occurrence, DOF experts and officers invite farmers to convene and discuss the measures to be undertaken.

In Viet Nam, training programs are being conducted focusing on topics that enhance the aquatic animal disease management capacity of veterinary officials from the central, regional, and provincial levels. These activities strengthen the capacity of the local aquatic animal health staff on legislation, disease surveillance and reporting, and response to disease outbreaks. Knowledge of veterinary epidemiology (*i.e.*, data analysis and disease warning), disease diagnosis, pathology, and biosecurity are strengthened during post-graduate education, in both local and international information-sharing networks.

Issues and Concerns

Cambodia has some issues on transboundary diseases for finfishes (*Gyrodactylus* sp., *Dactylogyrus* sp., *Argulus* sp., *Trichodina* sp., *Streptococcus* sp., *Aeromonas* sp.) and crustaceans (*Macrobrachium rosenbergii* infected by nodavirus/extra small virus (MrNV/XSV) and white spot syndrome virus (WSSV). Poor environmental conditions such as poor water quality in fishponds are regarded as one of the causes of persistent parasitic and bacterial disease problems and the emergence of new diseases.

In Myanmar, imported seeds including fish fry and shrimp larvae, are often of low quality and disease infected. The success of hatchery and farm operations is threatened due to poor management and the lack of technical know-how and technology that leads to disease occurrence. This situation has prompted the increase in the use of antibiotics and other chemicals which eventually increased environmental risks and highlighted the lack of adequate biosecurity control.

Although vaccines are already available in the market, vaccines for use in tropical food fish are limited and rarely used by small farms. Singapore is pushing for the use of autogenous vaccines, which are customized and herd-specific products. Although their efficacy is not assessed experimentally, the shorter development timeframe for such products is vital for the management of emerging diseases in food finfishes. There is still a need to develop regulations for the manufacture of autogenous vaccines and their use in tropical food finfish.

Several legislations that prohibit the use of antimicrobials have been issued by the responsible agencies in all AMSs. However, surveys still revealed the non-specific use of antimicrobials and other pharmaceuticals. The surveys imply that regulations and legislations are not properly implemented. The indiscriminate use of antimicrobials may lead to resistant strains of pathogens, thus resulting in the difficulty of treating diseases and the deterioration of the environment.

Although EPRS is already available in some AMS, its effectiveness still needs improvement through simulation exercises. There is also a need for the intensive training of individuals involved, including reiterating their roles and responsibilities.

Financial concerns seem to hamper the success of fish health management from disease diagnosis to EPRS. Brunei Darussalam mentioned that financial support is required to strengthen its EPRS. Cambodia fails to submit reports due to financial constraints, insufficient personnel, and training to improve the technical know-how in diagnostic capability and capacity.

Another issue that could hamper the success of fish health management is the insufficient awareness of the aquaculture industry players in matters related to aquatic animal health. There is a need to raise awareness among farmers of the importance of biosecurity measures, prevention of the spread of disease, local and import quality assurance (*e.g.* screening of stock, purchasing from accredited sources, and implementation of GAqP). Farmers are also not aware that not adopting GAqP which correlates to food safety and that the presence of food hazards in aquaculture products, could result in rejection in the international market and the banning of future export of products from the relevant country.

Way forward

The diverse educational backgrounds of farmers and their perception of the different aspects of aquatic animal health could be one of the challenges in fish health management. This concern could be addressed through regular conduct of activities on capacity building, information dissemination, and regular field consultation with local health officers. IEC materials are an efficient mode of awareness building since it can be illustrated, translated to local languages, and can be taken home by farmers for future reference.

Problems with transboundary and emerging diseases necessitate the formulation of new trade requirements within the region. Laboratory diagnostic capabilities and disease surveillance and monitoring programs should therefore be boosted. The existing networks reporting to WAHIS and Quarterly Aquatic Animal Disease (QAAD), and the transparent and prompt trans-national notification of new disease situations should be strengthened. The OIE and WAHIS system and QAAD reports to NACA are excellent platforms for the transparent reporting of country disease status. These systems will facilitate the timely notification of significant pathogen detections and the implementation of mitigation measures within the region.

Incorporation of water quality and other environmental issues in training courses, IEC materials, and laboratory services would help mitigate the effect of aquatic diseases. Aquatic animal health practitioners, as well as farmers, should understand the effect of environmental conditions on the general health of aquatic animals.

The capabilities of laboratory personnel in disease diagnosis can be enhanced through the twinning program of OIE. Personnel in satellite laboratories should also be trained for Level III diagnosis and equipment should be also upgraded in these laboratories.

7.1.3 Overcoming Fishmeal Dependence in Aquaculture

Fishmeal has traditionally been used as a primary source of protein in aquaculture feeds because of its high digestibility and well-balanced amino acid profile. Although global consumption has declined since its peak in 1996 (6.3 million mt per year), current rates are roughly three times of those 57 years ago and have been on a gradual uptrend since 2012 as shown in **Figure 100** (Indexmundi.com, 2021). The fishmeal consumption of the AMSs similarly peaked in 1999 at 1.9 million mt per year, before it gradually declined in subsequent years. In 2020, the AMSs collectively utilized 966, 000 mt of fishmeal accounting for more than 20 % of the global consumption rate.

The leading sources of high-quality fishmeal (Peruvian, Chilean, Danish) produced from small pelagic fishes like anchovies, scads, mackerels, herrings, and menhadens are the Latin American and the Nordic region. In Southeast Asia, Thailand and Viet Nam are the largest producers and exporters of fishmeal made from multispecies bycatch and trimmings (*e.g.* tuna) from the fish processing industry (Leadbitter, 2019).

However, the aquaculture feed industry's overdependence on fishmeal has both economic and ecological implications. Fishmeal is becoming more expensive as the rapid growth of the aquaculture feed industry pushes prices up. In Southeast Asia, trash fish or low-value fish bycatch are used as raw materials for fishmeal production as well as for human consumption, intensifying the demand for this resource strains the wild fisheries.

The adoption of alternative feed ingredients, especially protein sources, in aquaculture feeds is recognized as a viable option to reduce fishmeal overdependence and consequently to make fish farming more sustainable. Fishmeal substitutes and the status of their utilization in the region had been the focus of a consultative gathering of representatives from the AMSs in Myanmar in 2014 (Catacutan *et al*., 2015). Besides utilizing alternative feed ingredients in feed development, feed management strategies should be taken into consideration as it can also affect the profitability of aquaculture operations.

Use of Aquaculture Feeds

Several commercially important species are cultured in the region and their feeding habits, dietary protein

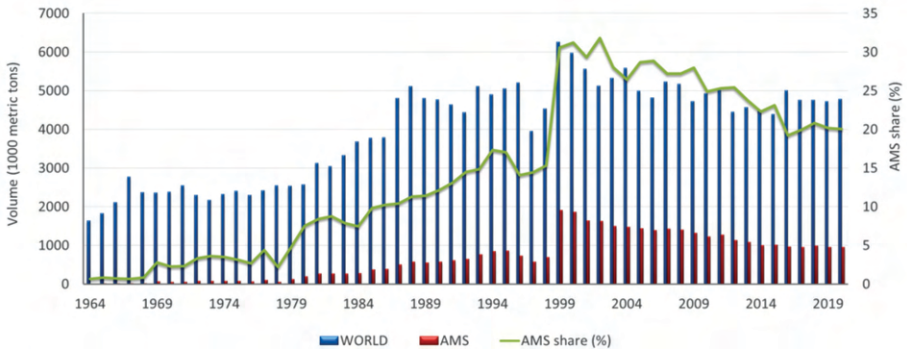

Figure 100. Fishmeal consumption of world and the AMSs from 1964 to 2020