AQUACULTURE with focus on Vietnam and Thailand

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With a focus on Vietnam & Thailand

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DISCLAIMER

PREFACE

Aquaculture is recognised as a rapidly expanding global industry, where production is expected to grow by >30% worldwide and surpass capture production by 2030. The production for fish and fishery products in South-East Asian Countries reached 20 Billion tons in 2008 and the Food and Agriculture Organisation of the United Nations (FAO) expect that production in this region will surpass 30 Billion tons. The fishing industry is a key sector of the national economies in the region, especially for Vietnam and Thailand where more than 6 million people are employed in the fishery sector.

The ERASMUS+ funded project TUNASIA (Tuning environmental competences in Asian fishery education for sustainable development) recognised the need for ongoing education and continuous professional development for those employed in the aquaculture sector to meet the increasing demand for aquaculture products (Figure 1). Partnering educational and aquaculture expertise the project focused on the modernization and development of curricula for the qualification of students in a transdisciplinary education system. One output of the project was the creation of this aquaculture textbook, with a focus on Vietnam and Thailand, to compliment the modernised bachelor and master's courses.

The information within the textbook provides both first-hand knowledge and a systematic collection of information from the latest scientific sources on aquaculture. For ease of reading, all the scientific references are confined to the end of each chapter. While this book has been written primarily to meet the needs of undergraduate and master students in the field of aquaculture, we hope that it will also be useful to a wider audience.

Figure 1 A crowded beach fish/seafood market in Vietnam (20941186)

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Erasmus+

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Contents

Abbreviations

ASEAN	Association of Southeast Asian Nations
AAs	Amino acids
ATPase	Adenosine Triphosphatase
ANFs	Anti-nutritional factors
cm	Centimetre
CF	Crude fibre
CPD	Carp pox disease herpes viral
DO	Dissolved oxygen
EFAs	Essential fatty acids
EC	European Commission
EMFF	European Maritime and Fisheries Fund
FAO	Food and agriculture organization
gal	Gallon
HPHN	Haematopoietic necrosis
ha	Hectare
Hb	Haemoglobin
IMS	Integrated mangrove-shrimp
IMTA	Integrated multi-trophic aquaculture
Kg	Kilogram
KSD	Koi sleepy disease
KHVD	Koi herpes virus disease
lb	Pound
m	Meter
MT	Million tonnes
NFE	Nitrogen Free Extracts
NAD	Nicotinamide coenzyme adenine dinucleotide
NADP	Nicotinamide adenine dinucleotide phosphate
PAS	Partitioned aquaculture system
PSU	Practical salinity unit
P/E	Protein and energy ratio
PUFA	Polyunsaturated fatty acids
RAS	Recirculated aquaculture system
SVC	Spring viraemia of carp
TUNASIA	Tuning environmental competencies in Asian fishery education for sustainable development
USD	United States Dollars
UV	Ultraviolet
WFD	Water Framework Directive
WSSV	White spot syndrome virus

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1 Introduction

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World aquaculture production: Global fish production (including crustaceans, molluscs and other aquatic animals, but excluding aquatic mammals, reptiles, seaweeds and other aquatic plants) peaked at 179 million tons in 2018, thanks to aquaculture. Aquaculture accounted for 46% of the total production with 52% for human consumption. The total value of farm-gate sale of aquaculture production, dominated by finfish, has reached a high of USD 263.6 billion. In 2018, the majority of aquaculture production came from inland waters, accounting for 62.5 percent of the world's farm fish production. Furthermore, marine fish production reached over US$150 billion at farm-gate value, which was higher than that of the global beef industry. Aquaculture is witnessing a fast-growing phase, with an approximate 6% increase annually.

In 2017, world production (425 cultivated species) supplied over 80 million tons of fish and shellfish, and 32 million tons of seaweeds. As defined by FAO a species item refers to a single species, a group of species (where species level identification is not possible) or an interspecific hybrid. Despite the high diversity of farmed species, aquaculture production by volume is dominated by a small number of 'key' species or species groups at national, regional and global levels. Finfish farming, the most diversified sub-sector, was based on 27 species and species groups accounting for more than 90% of the total production in 2016, while the top 20 species accounted for 84.2% of the total production. It is thought that 75% of global aquaculture production largely comprised of seaweeds, carps, bivalves, tilapia and catfish.

Aquaculture production in Asia: World aquaculture production of farmed aquatic animals has been dominated by Asia, with an 89 percent share in the last two decades or so. Among the major producing countries, China, India, Indonesia, Vietnam, Bangladesh, Egypt, Norway and Chile, have consolidated their share in regional or world production to varying degree over the since the 1990s. Asian producers contributed 92% of all live weight per volume, of animals and seaweeds in 2017. Asia aquaculture supports a diverse range of farming systems and species in comparison to other regions. For the Southeast Asian countries alone, aquaculture production was projected to grow at a rate of 107% during the period 2010-2030.

Aquaculture has a long history in Asia, with its earliest traditional farms found in inland followed by a move to brackish water areas much later. Traditionally inland aquaculture in Asian countries typically coincided with some forms of agricultural activities such as rice and vegetable productions. These have since been developed or modified becoming a popular aquaculture system and often include rice-fish culture or husbandry-garden-fish pond systems (known as V.A.C in Vietnam). Such traditional fish farming mainly produce fish for domestic consumption. These systems are recognized worldwide due to their many advantages such as optimization of nutrients, mitigation of negative impacts to the environment, a low capital investment providing opportunities for poorer small-scale farmers, and other socio-economic benefits. In terms of brackish aquaculture, there are also many traditionally typical farms which strongly support the economy of the Asian countries at different levels. For example, the currently well-developed milkfish culture systems in many countries like the Philippines and Indonesia are believed to have started centuries ago, and now have become an important sector for both local and export markets. Another integrated aquaculture system in brackish water known as aquasilviculture was initially developed in Myanmar 70 years ago (Ahmed, et al., 2018); a type of multi-species (including finfish, shrimp, crab, etc.) aquaculture, integrated within mangrove forests which are used as biofilters. The aquatic products rely largely on natural seeds that come into the ponds with the tidal currents. Integrated mangrove-shrimp (IMS) aquaculture is a sustainable farming system used as one of the measures for mangrove rehabilitation. Artificial seeds of targeted shrimp species are often additionally released to the system, in order to improve shrimp production. This system has become a popular practice in many countries such as the Philippines, Malaysia, Indonesia, Thailand, Vietnam, etc.

A variety of aquatic species are raised in Southeast Asian countries with the top farmed groups of species being shrimp (22%), catfish (13%), milkfish (11%), carp (10%), tilapia (10%), miscellaneous freshwater fish (20%) and others (14%). Furthermore, aquatic plants significantly contribute to the aquaculture production in some countries of the region. In the Philippines and Indonesia aquatic plant production is often double that of farmed aquatic animals. Conversely, Cambodia, Malaysia and Vietnam produce only very small amounts of aquatic plants in comparison to aquatic organisms.

System classification: Aquaculture can be classified into various production systems relying on raised species, environmental characteristics, types of facilities, levels of identification and so on. In terms of environment, an aquaculture farm can involve freshwater, brackish water or saline water, which support different species accordingly. There are also many different facilities used for fish farming, which decide how the raised species interacts with the surrounding water bodies. The most commonly used facilities are ponds, cages, pens, tanks, raceway systems for aquatic organism, and stakes, rafts, longline for plant cultivation. Each type of facility is also constructed with different materials, which influence its building cost, lasting duration, management etc. For example, a fish cage can be made of wooden net or synthetized fibre net with the later allowing a faster water exchange. As a result, the synthetized fibre net cage can be stocked with a higher density of fish. However, the selection of material depends on several factors such as the farmers' investment ability and stock availability etc. Each aquaculture system has different ecological, social and economic impacts. Not having standardized farming practices that can be easily classified, codified, labelled or regulated means that it is important that the aquaculture industry firstly defines the systems structure, functions and hierarchical placement prior to addressing its ecological, social and economic linkages and impacts.

It is commonly agreed that integrated multi-trophic aquaculture (IMTA) increases sustainability through the three dimensions of economic, social and environmental aspects, especially with the integration of extractive species like seaweed and molluscs. In particular, it creates additional value products, improves water quality, prevents diseases, and conserves habitats etc. However, it has been argued that integration may not create significant economic profit to the farmers in some cases because of its low market value products. Integration of species from different trophic levels also increases the complexity of the farm which in turn will require good management skills. The overall benefits seen from integrated aquaculture is strongly reflected in the increasing practice of IMTA worldwide and especially in Southeast Asia. The World Bank stated that "Aquaculture, done in a socially and environmentally friendly manner, is the only way to meet the growing demand for seafood, while also creating jobs, generating revenues and taking pressure off over-stretched capture fisheries".

Constraints in aquaculture and sustainable solutions: In line with the rapid expansion of intensive aquaculture of mono species during last few decades in the Southeast Asian countries including Vietnam, aquatic habitat degradation and water pollution have challenged the sustainability of this sector. For instance, in Nha Phu Lagoon located at the Central Vietnam as well as in many other areas of the country, intensive shrimp farming experienced severe environmental pollution and disease outbreaks, which led to a vast number of farmers becoming bankrupt. Hence, they have moved to IMTA systems often integrating shrimp with other animals and plants. Furthermore, this intensive farming has seen negative impacts from the effects of climate change, where large fluctuations in environmental parameters lead to increased infection rates of disease on raised organisms; often leading to low productivity as a consequence. To manage this, more closed systems are in operation, such as super-intensive shrimp farming, which use biofloc technology with reduced water exchange, minimizing interaction with surrounding waters. This system is showing promising results in Vietnam for shrimp farming in terms of reducing both the environmental impacts on the environment and the impacts on shrimp health. Furthermore, the system is seen to be extremely high productivity, e.g. producing in the range of ten to one hundred tons of shrimp per ha annually. However, this model requires very high capital investment that limits access for small-scale farmers.

One of the major threats facing aquaculture in Asia is impacts of climate change. While climate changes are expected to impact aquaculture production in different ways Vietnamese farmers are adapting and introducing new strategies. A recent study examining the Vietnamese shrimp industry claimed that super-intensification of white-leg shrimp production ("closed system") would be a sustainable solution to achieve the government target of becoming a global leading shrimp exporter that meet the international market demand in terms of both quantity and quality. The authors reported that a small-scale farm applying this model can normally obtain 20-25 tons/ha/cycle, which is 5-7-fold of that from a traditional intensified farm ("opened system") in the Mekong Delta of Vietnam. In addition, the super-intensive farm would potentially eliminate the known weaknesses of common shrimp farms, such as exposure to disease, infections, water pollution, and the impacts of climate change. However, to practise super-intensive shrimp farming, it requires a very high capital investment which hinders most of the small-scale farmers in Asia. Solutions to this include the establishment of collaborations amongst small-scale farmers, providing supports from different private sectors (input suppliers, banks, processing industry), changing the governance framework with supporting policies and institutions, etc.

Focus on Thailand and Vietnam: Thailand and Vietnam are two of the biggest aquaculture producers in the Southeast Asia. The following figures and information provide an insight into the different trends of aquaculture development. Statistical data by IBRD-IDA show that aquaculture production was similar during the 1960s until 1987, with each country producing about 30,000 metric tons in 1960 and over 140,000 metric tons by 1987. From 1988 to 2004, Thailand saw an increase in production higher than its counterparts in Vietnam. However, from 2005 Vietnam led production for first time and today continues to be significant producer in Asia. During this period the country saw aquaculture production rates increase between 3.6 to 26 percent annually. Its production in 2018 was over 4.1 million metric tons in comparison to approximately 0.9 million metric tons in Thailand. In terms of acreage, Thailand used only about 199,470 ha of land for aquaculture in comparison to Vietnam where in 1995 used 453,000 ha which doubled by 2013 and according to the National Master Plan expects to expand this are further to 1,200,000 ha.

Of the total land area for aquaculture in Thailand, freshwater farms occupied the most, accounting for 61%, while in Vietnam aquaculture land was dominated by brackish water farms. For example, coastal shrimp farms alone occupied 685,000 ha in 2014.

Vietnamese aquaculture targets 9 major species or groups, i.e., black tiger shrimp (*Penaeus monodon*), white-leg shrimp (*Litopenaeus vannamei*), Pangasius catfish, tilapia, giant freshwater prawn, marine fish, marine mollusc, seaweed and lobster with aquaculture production dominated by Pangasius catfish and shrimp (tiger and white-leg). In 2020, production of Pangasius and shrimp was 1.56 million and 950,000 tons, respectively. Similarly, raised species in Thailand were diverse, with the major groups including Penaeidae species (mostly tiger and white-leg shrimp) accounting for 38% of total production, Mytilidae family (green mussel and horse mussel) sharing 15%, Tilapia family (Nile tilapia and Java tilapia) at 15%, and walking catfish. In both countries, the traditional farming of black tiger shrimp was gradually replaced by white-leg shrimp as a consequence of disease outbreaks. The white-leg shrimp was first introduced as an aquaculture species to Thailand in 1998, and Vietnam in 2002. The production of this newly farmed species rapidly eclipsed that of the black tiger shrimp even with smaller farming areas. In fact, the total area of black tiger farms in Vietnam plateaued at about 600,000 ha of land and 260,000 tons of production between 2013 and 2017, while the white-leg used around 100,000 ha but produced nearly 300,000 tons in 2013 and 400,000 tons in 2017.

The breadth of material this book covers includes wide range of issues related to aquaculture production, including its development history, farming systems and technology aspects, seed production, feed and feeding, health management, genetics and selective breeding, climate change impacts, etc., with a focus on the Southeast Asian region of Thailand and Vietnam (Figure 2, Figure 3).

Figure 2 Cage aquaculture farming in Thailand (13974390)

Figure 3 Shrimp hatching pond Mekong Delta in Vietnam (15219730)

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2 Aquaculture Systems

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Aquaculture is the farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants, through individual or corporate ownership of the organisms being cultivated. Aquaculture takes place within organised systems involving key changeable and interrelated elements (e.g. stock level, water, temperature, nutrients, etc), for the breeding and rearing of aquatic organisms. Farmers intervene in this rearing process to enhance production, through for example regular stocking, feeding, protection from predators, etc.

In order to address and understand the different and often specific areas within an aquaculture system a holistic perspective, at the most basic, is required which will reveal the interrelations and trends often associated with different species.

Aquaculture is extremely varied in terms of, not only what species is farmed, but also in which system they are raised. This chapter focuses on the different aquaculture systems found in Asia.

2.1 Aquaculture systems

Aquaculture operations are often diverse, and this can result in the description of the complex systems leading to confusion. The classification of an aquaculture system is based on several criteria including the final aquatic product (fish, crustaceans, molluscs and/or seaweed); the water mass (lentic and lotic) and level of salinity (fresh, brackish, marine water); the water temperature; species composition; nature of culture facilities and the level of intensification or integration (within and with other systems, household and community level).

2.1.1 Aquatic environment

The culture of organisms requires that the aquatic environment in which they are naturally found in nature i.e. the level of salinity (freshwater, brackish water and marine) is replicated in the aquaculture system.

Freshwater aquaculture

Freshwater can be defined as water with less than 0.5 PSU (Practical Salinity Unit). Freshwater aquaculture refers to the raising and breeding of aquatic animals (fish, shrimp, crab, shellfish, etc.) and plants native to freshwater environments for economic purposes through the use of ponds, reservoirs, lakes, rivers, and other inland water bodies.

Marine aquaculture

Marine aquaculture refers to the breeding, rearing, and harvesting of aquatic plants and animals (primarily oysters, clams, mussels, shrimp, salmon, and other marine fish) native to saltwater environments which have a salinity of more than 30 PSU. It can take place in the ocean, or on land in tanks and ponds.

Brackish water aquaculture

Technically, brackish water is a mixture of fresh and saltwater which usually occurs in coastal areas and has a salinity usually of between 0.5 and 30 PSU, depending on rainfall and freshwater run-off. It is characteristic of many brackish surface waters that their salinity can vary considerably over space or time. Brackish water aquaculture refers the production of fin and shellfish native to brackish water environments (creeks, lagoons and estuaries).

2.1.2. Aquaculture structures

The type of structure refers to the housing where they are either enclosed or separated from natural populations. Common aquaculture structures include ponds, tanks, raceways, cages and pens.

Earthen ponds

Earthen ponds are mostly man-made and can be any shape but tend to be shallow (<2 m in depth) and rectangular with muddy bottoms to allow for ease of fish harvesting with seine nets.

The ponds can be used for fish spawning, fry nursing and holding, grow-out and overwintering (Figure 4). In a fish farm, the grow-out ponds are larger than the others and generally may constitute about 85% of the total pond area. Pond systems tend to be less intensive because there are not many technical requirements.

There is limited control of environment factors, especially of physical characteristics such as temperature, in a pond system, however, natural feed can be utilized through the addition of fertiliser to enhance fish rearing. Yields from culture ponds can range from a few hundred to several thousand kilograms per hectare, depending upon fish stocking density, feeding rate, and management. High yields require large volumes of high-quality water, stable environmental conditions, supplemental aeration and/or oxygenation, high quality feeds, and good management.

Figure 4 Striped catfish nursing in earthen ponds (Nguyen Van Tu)

Raceways

Raceways, the pioneer for intensive production, are usually comprised of narrow linear channels made up of two to three ponds (culture units) in a series (Figure 5). A pond is typically about 30×3×1 m. It may be smaller or larger. High quality water continuously flows into these culture units and passes through the heavily stocked raceways, which hold the fish. Due to fast water flow rates the raceways are constructed from cement and are located above or in the ground. Different from the earthen ponds, fish stocking in the raceways is high and natural feed is unavailable. Each raceway will have several feeding stations with fish waste discharged from the downstream end of the system.

Concrete or fiberglass tanks

The tanks tend to be round, oval or rectangular in shape (Figure 6). The water inlet is designed to move the water towards the centre of the tank by creating a circular motion by entering through a round spout. As a result, the draining of the waste is through a centre standpipe drain enclosed by a screen. The round tanks are usually 4m in diameter, with a depth of approximately 1m. The stocking densities depend on the water inflow and aeration. In tanks where the water is changed every 1-2 hours, the highest stocking rates are approximately 25-50 kg/m^3 and up to 150 kg/m^3 with aeration. Many fish farmers use complete feed to feed fish, this is usually compromised of 30-35% crude protein for growing-out fish. A tank system is superior in terms of hygiene and management because the production is concentrated in a small space. However, the investment cost for a tank system is high for necessary facilities and equipment.

Figure 5 A Raceway System in Australia (Lê Anh, Tuấn)

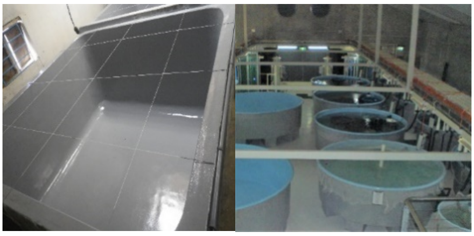

Figure 6 A concrete tank for finfish nursing in Vietnam (left) and a Fiberglass Tank System in Australia (right) (Lê Anh, Tuấn)

Floating cages, pens and enclosure

Cages are floating structures constructed traditionally of wood or in more recent times of net. They come in many shapes including circular, square or rectangular. Floating cages are located in open water (Figure 7). They range in sizes depending on their overall design, purpose and site characterisation. These environments are used for fish in their grow-out phase where they grow until they are of marketable size.

Pens and net enclosures (hapas) are simple enclosures in shallow water environments. They usually take place in ponds confining them inside the enclosure and are used for the rearing of aquatic animals and plants. They are usually small in size at a maximum of 10 square meters. The enclosures framework is made up of mangrove branches, wire, wood, mesh and bamboo. This type of aquaculture system is mainly practiced in developing countries.

The use of mesh material fences or walls are used to enclose bottom-dwelling scallops in pens, and these are tall enough to stop the scallops from escaping over the wall. In addition, floats can be used to hold the mesh up, so it rises and falls with the tide.

Net enclosures (hapas) are mainly built using mesh or mosquito netting made from fine synthetic fabric. Hapas are very easy to manage so they can be used for fish nursing. This creates an easier environment for harvesting fingerling where the fry cannot escape. Hapas can come in square or rectangular shapes in manageable sizes of 1-40m^3 and at depths ranging from one to two meters.

Figure 7 A Traditional Seacage Farms in the Van Phong Bay-Vietnam (Lê Anh, Tuấn)

2.1.3. Water exchange

Water exchange can be classified according to one of four types namely static, open, semi-closed and recirculating (closed).

Static systems

Traditional pond culture practices are used by most of the world for aquaculture production. There is no water exchange during the cultivation period with these static ponds. Water may be added to supplement the system in order to compensate for any potential loss through evaporation. Aquaculture in static ponds is generally extensive due to the major problems to maintain an optimum environment for farmed fish where large amounts of fish per unit volume of static water can cause water quality issues.

The more farmed fish stocked in these systems the larger amount of feed and fertilisers that are required to maintain optimum growth. The management of water quality is required due to this increase. The water quality issues include unacceptable levels of nitrogen compounds and low levels of dissolved oxygen during the night. The addition of aeration can help control the dissolved oxygen (DO) with a larger biomass to maintain or increase productivity. The challenges faced with aerators are the cost and availability in rural areas where many static ponds residue.

Open systems

Production systems in this category are based entirely on natural ecological processes. These systems are normally natural water bodies which are now stocked for commercial production. Many of these systems could be viewed as stock enhancement rather than aquaculture. Biomass densities are generally low enough that natural processes can provide enough oxygen for the supported biomass. The oxygen can come from diffusion, photosynthesis by communities of natural algae, or both.

Figure 8 An Oyster Farm in Australia (Lê Anh, Tuấn).

Waste is also eliminated by natural processes within systems and the decomposition of solid waste is due to bacteria and heterotrophic fungi. Production methods that operate in an open system environment include shellfish farming systems, cages, net pens, sea ranching and reservoir ranching (Figure 8).

Semi-closed systems

In this category, we still rely heavily on nature to provide the three ecological services of appropriate temperature, sufficient oxygen and waste disposal. However, in the semi-closed category, the production units themselves are now largely man-made. Production methods in semi-closed systems include ponds and raceways. Within the production units, we now have the possibility to add or remove water. There is a larger contribution by the management in these systems, and the first steps towards complementing or improving the natural processes exist in these systems, as well. In semi-closed systems, water comes from a natural source such as rainfall, springs, streams or rivers. The water is then poured by gravity or pumped into specially designed and built production units. Water can be used once and discharged or constantly cleaned and re-oxygenated by natural processes. Compared to open systems, semi-closed systems have several advantages one of which is much higher production rates, up to 1000 times the productivity of an open system. This is due to the increased control and inputs into these systems and the fact that their physical parameters can be maximized for greater productivity.

Closed systems

In closed systems, the water is reused in an artificial culture system. In addition, there is human intervention of a certain type and at a certain level for all key processes. The main benefit of closed systems is that they allow for all environmental compartments to be controlled. The negative aspect of closed systems is that all these compartments must be regulated correctly as the operator is solely responsible for all aspects of the cultured animals' environment. In closed systems, the water temperature can be kept very close to the optimum growth temperature for the farmed animal. This can have an extremely positive impact on the growth rate and efficiency within these systems. The control of temperature allows for tropical species to be cultured in non-optimum climates, if desired by consumers. Heat in the form of waste from industrial processes can be of economic benefit if timing and closeness of the systems are compatible. The water in closed systems can reduce pathogens by being continuously disinfected by ultraviolet (UV) lamps or ozone. It allows for the eradication of both poachers and predators, eliminates external environmental threats such as flooding or short periods of cold weather, and allows for the addition of quality feed effectively and for the monitoring of consumption and conversion. The amount of water becomes less of a worry but for large systems a loss of more than 5% of their total water volume per day (for maintenance reasons) can still become substantial.

Closed systems include biofilter-based systems and heterotrophic or biofloc-based systems. Biofilter-based systems or recirculating aquaculture systems (RAS), recycle systems and intensive recycle systems. These types of systems use the same water over and over again.

Recently there has been a new system developed where water again stays in a closed circuit. The newly developed system is colonised by heterotrophic bacteria that eat organic waste instead of depending on chemo-autotrophic nitrifying bacteria, which use inorganic compounds such as ammonia for energy. The heterotrophic bacteria are not restricted in the biofilters but are present in the culture vessel at the same time as the animal in culture. Production rates can be enhanced to > 5 kg/m^3 when the population of the bacteria has been established and stabilised. The demand for oxygen is very big in these systems. The nitrogenous waste released by organisms can be eliminated by the systems converting it into bacterial biomass. The quick removal of solids is essential to the function in traditional RAS. The solids are kept in the culture tanks and colonised by heterotrophic bacteria, protozoans, fungi into suspended particles known as bioflocs in these heterotrophic or biofloc systems. The cultured animals can graze on the bioflocs, which recycle the waste and can be directly consumed as a protein-rich fodder.

Hybrid systems

New approaches over recent times make it harder to tell the difference between the different production systems, including the main categories (open, semi-closed and closed). The use the best features of different systems combining them to one and eliminating the flaws of one, capitalize on the positives of the other, or divide a system into its functional components so that they can be individually handled. These hybrid systems include aquaponics, in-pond raceways, and partitioned aquaculture systems.

In a system called aquaponics water is continuously recirculated through the system. Although it is slightly different to a regular recirculatory system as plants replace the biofilter which convert waste and produce marketable plant products in return. Aquaponics systems are becoming more and more attractive in areas where water availability is limited. In-pond raceways are similar to cages floating in open system waters or semi-closed pond systems. However, they take on the characteristics of a raceway by constantly flowing water through cages by mechanical means. In-pond raceways allow the fish to be confined in small systems so that they can be fed and monitored more effectively (like a raceway). They also give at least the potential to capture waste for disposal, again like a raceway. However, unlike regular raceways, these systems are not limited to locations with large groundwater springs or flowing surface water resources. These "raceways" can be located wherever large ponds or reservoirs exist. The temperature and waste removal functions of these systems are still managed by the same pond processes. The oxygen requirements of these systems are also mainly addressed by the pond system. However, since fish are confined at much higher densities, the supply of dissolved oxygen is usually supplemented by mechanical aeration, and sometimes by addition of pure oxygen. With the Partitioned Aquaculture System (PAS), the concept of a pond as an algae-driven system is modified to address one of the limiting factors of a traditional pond. In heavily fed ponds, dense plankton blooms develop, and light cannot penetrate deeply, so that only the upper level of the water column is fully functional (i.e. it has enough light for photosynthesis). By taking the water and circulating it in channels that are only 40 to 60 cm deep, most of the water volume receives enough sunlight to be productive, allowing threefold to fourfold production increases in the same area and volume. The PAS is not so much a hybrid system as it is a "deconstruction" of a pond-based system into its functional components so that each component can be modelled, and its efficiency maximized. It is still essentially a pond system. However, primary culture fish are now confined to a cage similar to an in-pond raceway.

2.1.4. Intensity of Aquaculture

The aquaculture intensity can be classified by the range of densities of organisms per unit of volume or per unit of area. The culture levels of a species or related species is important in comparisons between them. Although, comparing the densities of different groups of organisms is not useful. For example, in a recirculating system the culture of tilapia at 100 kg/m^3 of water is thought to be an intensive culture whereas in ponds the culture of shrimp at 50 organisms per square meter (1–2 kg/m^3) is also thought to be an intensive culture. The inputs needed for the maintenance to sustain the growth of the cultured organisms will be taken into account by the intensity of culture. The word "intensity" relates to this as the increase in intensity/density of cultured organisms sets the need for the increase in the inputs required in the system.

Extensive culture system

Extensive culture is different to other systems as it takes place in a natural habitat and relies mainly on the surrounding environment for maintenance and requirements. An extensive culture is more basic on a husbandry level, adding fertilisers but no aeration, therefore illustrating that the inputs are reduced greatly in terms of maintaining fish growth and survival.

Extensive culture systems generally involve large ponds of 1 to 5 ha in area with a low stocking density (<500 fish/ha). The natural productivity of food (plants and animals) within the system and the exchange of natural gas is sufficient to support cultured organisms. Low intensity aquaculture producing only a moderate increase compared to natural productivity. There is no addition of supplementary feed for the fish, survival is based on the natural availability of food. This method of fish farming requires the least amount of effort. The yield is poor (0.5 to 2 tons/ha) and the survival is low. The labour and investment costs are low, and this system results in minimum income.

Semi-intensive culture system

Semi-intensive culture mainly takes place in pond systems and its purpose is to increase the production of fish, allowing for the stocking density to be increased by 2-3 times in comparison to conventional ponds (Figure 9). The natural productivity of the pond can be enhanced by adding inorganic or organic fertilisers, the addition of aeration to maintain dissolved oxygen levels and the aerated area should cover the pond area by approximately 10 to 15%. The addition of supplementary feed is required along with the natural food available to the organisms in the pond. This type of culture is promising for developing countries e.g. semi- intensive culture of tilapia making capital investment and management options available. The improvement of DO levels and natural productivity can be seen in management at lower intensity level. The stocking density varies between 5 and 10 fish per cubic meter. The fish yields of these techniques have been found to be higher than those of natural unfertilized systems. This type of fish farming is more common all over the world and includes smaller ponds (0.5 to 1 hectare in area) and a larger stocking density (10,000 to 15,000 fish per ha). In semi-intensive fish farming systems natural foods are developed by fertilisation with or without supplementary feeding but natural food available in the ponds remains the main source. Survival rate is high with the yield being moderate (3-10 tons per ha).

Figure 9 Semi-intensive shrimp culture in earthen ponds (Nguyen Van Tu).

Intensive culture system

High intensity aquaculture gives a far excess compared to conventional culture. In this type of aquaculture, the pond must have aeration facilities that cover half of its area as the stocking rate is much higher (Figure 10). The fish diet depends only on the complete diet (diet rich in protein). These intensive aquaculture systems can take place in cages, ponds, raceways, tanks, in tropical, subtropical and temperate regions. The conditions of the water quality needed by the cultured organism is the deciding factor on the maximum stocking density. In general, ponds and cages have the lowest stocking densities and raceways and tanks have the highest. Natural systems and intensive systems are opposites of each other.

The food chains are basic as requirements only involve feeding the cultured organisms. There are little energy losses from the input of feed. There is no recycling of energy and it is not self-sufficient. High energy inputs include feed, aeration, pumping, nutrients and filtrating. There are high yields per unit area.

Generally, high exchange rates maintain the water quality and sometimes by mechanical means. In indoor intensive systems such as tanks, removal of waste, oxygen production and gas exchange are enhanced by mechanical means. In intensive systems outdoors that have soil substrate and phytoplankton, particulate waste can build up, decomposition by bacteria and gas exchange carried out by mechanical aeration. The stocking density (mass of the culture stock per volume or area of water surface, expressed in kg/m^3 or kg/ha) in intensive systems varies considerably according to the type of organism cultured and the type of system in use but regardless is generally high.

Generally, a maximum fish production with a minimum volume of water is achieved in intensive fish farming methods that are managed well. This type of system includes raceways, tanks and ponds that have high stocking densities (10-50 fish/m^3 of water). The fish in these systems are fed with formulated feed. Good management efforts include the addition of nutrition using healthy feed and air using aerators to ensure good water quality in the system. The yield achieved ranges from 15 to 100 tons per hectare or more.

Figure 10 Intensive shrimp culture in earthen ponds (Nguyen Van Tu).

2.1.5. Fish Farming Methods

There are two well know farming systems namely monoculture and polyculture systems in operation.

Single species aquaculture system, briefly *monoculture*, grows only one species. The culture of single species of fish can be in a pond or tank. The advantage of this method of culture is that it enables the farmer to make the feed that will meet the requirement of a specific fish, especially in the intensive culture system. Fish of different ages can be stocked thereby enhancing selective harvesting.

Multi-species aquaculture system, briefly *polyculture*, is the practice of culturing more than one species of aquatic organism in the same pond. The motivating principle is that fish production in ponds may be maximized by raising a group of related species or raising species from multiple levels of the food chain (trophic levels). The mixture of fish gives better utilization of available natural food produced in a pond. Polyculture began in China more than 1000 years ago. The practice has spread throughout Southeast Asia, and into other parts of the world. Ponds that have been enriched through chemical fertilization or feeding practices contain abundant natural fish food organisms living at different depths and locations in the water column. Most fish feed predominantly on selected groups of these organisms. Polyculture should combine fish having different feeding habits in proportions that efficiently utilize these natural foods. As a result, higher yields are obtained. Efficient polyculture systems in tropical climates may produce up to 8000 kg of fish/ha/year.

2.2. Production systems

2.2.1. Pond culture

Ponds are commonly defined as small, confined bodies of standing water. Most ponds are used to grow aquatic animals.

An aquaculture pond can be defined more fully as an aquatic organism culture system that due to a long hydraulic residence time, the water quality needed for organism production is controlled mainly by chemical, biological and physical processes within the water body.

Pond aquaculture comprises a wider range of culture species, environments, water sources, resource input levels, and environmental impacts than any other aquaculture systems. Pond aquaculture systems can be classified based on criteria such as ultimate use of product (food fish, ornamental fish, sport fish, baitfish), species of animal (carp, catfish, shrimp), life stage (larval, fingerling, food fish), salinity preference (freshwater, brackish water, saltwater), and climatic or temperature regime (tropical, warm water, cool water, cold water).

Levee, or embankment, ponds are the most common type used in aquaculture. They are built on flat land by excavating a thin layer of soil from the pond bottom and using that soil to form levees or embankments around the pond perimeter. Filling and emptying the ponds can be based on tides or pumps. Excavated ponds are similar to embankment ponds, with respect to general construction and primary water source, but are usually smaller and the elevation of the pond bottom is further below the original ground level of embankment ponds. Filling the ponds can be partly with inflow from groundwater or nearby surface waters but emptying water may require pumping to lift water into drainage canals. Watershed ponds are built in hilly terrain by damming a temporary or permanent stream. The major source of water is runoff from the catchment basin above the dam.

Aquaculture ponds are usually constructed of soil and typically shallow (<2 m), so interactions between soil and water have important effects on water quality. In some areas with loose structure and problems of soils, the ponds may be lined with plastic or other impervious materials to reduce water loss from seepage and to maintain water quality.

There are many factors contributing to pond water quality. Water temperature, the most important environmental factor affecting aquaculture production is driven by solar energy. It varies in seasonal and diurnal cycles. Therefore, the control of water temperature fluctuation in ponds is impossible. Besides temperature, pond water quality is also influenced by other environmental variables and also varies in seasonal and diurnal cycles due to biological activity, particularly photosynthesis of aquatic plants and respiration of aquatic animals and plants. Dissolved oxygen concentration normally increases during the day and decreases at night; on the contrary, carbon dioxide concentration normally decreases during the day and increases at night. pH, depending on the carbon dioxide concentration, increases during the day and decreases at night. The management of pond water quality by controlling these variables is difficult, impractical, or expensive. For example, using mechanical aerators to supplement dissolved oxygen in pond water is costly. In the context of quick variation of water variables, aquatic animals which highly tolerate a relatively wide range of environmental conditions are best suited to be grown in ponds.

Aquaculture ponds may be filled with fresh, brackish, or saltwater depending on selected species to grow. Pond aquaculture can be practiced at different intensity levels. Ponds can be used to grow fish for subsistence consumption and livelihood improvement at a low input and small scale or to grow fish or crustaceans for generate profit at a high input, large and commercial scale.

2.2.2. Cage culture

The use of cages as an aquaculture method is used to restrict the cultured species to one area, allowing high densities and eliminating interactions from other species in the water body outside the cage. Strictly defined, cages are rigid structures or have a frame on which the netting or mesh is held in place. The water bodies the cages are placed in provide most basic functions needed to sustain culture. Cages depend on water movement through them (from the water body) to supply the culture organisms with water of sufficient quality for sustained growth and to remove problematic metabolic wastes.

The concentrations and variability of water quality parameters depend on the water body, currents, and any external inputs. In particular, the delivery of dissolved oxygen and the removal and decomposition of wastes from cages depend on the water body and its physical, chemical, and environmental characteristics. Therefore, the success of cage culture is very dependent on the water body in which the cages are placed and environmental impacts on that water body from the culture practices, the climate, water quality, and possibly human activities.

Advantages of cage aquaculture include the exploitation of almost any existing water body (e.g., ocean, bay, estuary, river, lake, or pond); relatively low construction costs compared to building ponds, raceways, or recirculation systems; observation, feeding, and harvest are relatively straightforward; and disease treatment (if necessary) can be effected more accurately and economically.

Most disadvantages associated with cages can be attributed to the relatively high densities that culture species are stocked. These can include crowding related abrasions, rapid disease spread, localized water quality issues, attractiveness to predators and poachers, and communal interactions of the cultured species that may cause reduced growth. Fouling of the cage netting is also a common problem. Fouling caused by algae or sessile organisms can diminish the volume of the cage and severely decrease water flow circulation through the cage. In addition, cage culture has little or no control over water quality parameters like temperature, pH, alkalinity, and hardness. Dissolved oxygen can be supplemented with aeration or circulation devices.

Cages have been utilized for all stages of aquaculture production: holding broodstock, spawning, rearing fry and fingerlings, and production of foodfish. Cage mesh size is chosen based on the size of fish at stocking and often fish are moved to cages of larger mesh size as they grow.

Cages can be categorized as extensive, semi-intensive or intensive based on their stocking density and source of food. Extensive cages receive no external feed and rely on only natural foods such as plankton (phyto and zoo), seston, and detritus. The species cultured extensively have been primarily carps and tilapias. Semi-intensive cage culture is very common in freshwater systems in tropical climates. In addition to available natural foods, the fish are fed other (usually nutritionally incomplete) foodstuffs. Like extensive culture the species commonly cultured include the tilapias and the carps (i.e., silver, bighead, grass, and common). Intensive cage culture requires the use of nutritionally complete feeds. Intensive culture usually is limited to high-valued species because of the cost associated with feeding. In freshwater these include catfish (Ictalurids and Pangasids), salmonids, snakeheads, carps, and tilapias. In marine waters, species cultured include salmonids, seabass, seabream, yellowtail, amberjack, cobia, and croaker. Increasing interest in cage culture of other marine species such as tuna, grouper, and snapper has begun.

2.2.3. Flow-through raceway culture

Raceways are essentially large artificial earthen or concrete troughs. A typical length: width: depth ratio in linear raceways is 30:3:1. High quality water gets into and through the trough, providing needed oxygen and rinsing out wastes. Water sources are usually ground waters coming to the surface in the form of springs or surface water from snow melt or rain runoff from higher altitudes. The water can often be reused several times because the water flows through several raceways in series. Inputs are in the form of high-quality feeds, simple aeration between pipes, cleaning of raceways, size grading of the animals, and easy observation of the fish for disease problems and efficient feed utilization. Raceway production is very intensive in terms of land use. Per hectare, a surplus of 300 tons of fish can be produced per year. However, these systems require a lot of water. To produce 1 kg of trout in a raceway requires 98,000 litres of water, compared with 1,250 to 1,750 litres to produce one kg of catfish in a levelled pond. Because of this extremely high-water demand (> 1,500 Lpm), the siting of commercial raceway operations is almost entirely dictated by availability of appropriate water resources. An appropriate source must provide sufficient volumes of water at correct temperatures constantly, all year round.

In raceways, the oxygen is supplied by incoming water. It must come into the raceway saturated with oxygen. If groundwater is used, it must come from unconfined underground spaces where it has been closely exposed to air. If the water has been confined between layers, it may have low oxygen levels and be supersaturated with certain unwanted gases.

Wastes produced in these systems are passed on for being treated further downstream in the receiving water or on site in designed treatment units. Temperatures in raceway systems reflect their source of water. Retention time is low, the temperature therefore changes little in the system. Raceways using groundwater have water temperatures identical to those of the region's groundwater, which is directly correlated to proximity to the equator. Exceptions include raceways using surface waters or deep source geothermal waters.

2.2.4. Recirculating aquaculture

As mentioned previously, recirculating aquaculture systems (RAS) are systems where water stays in a closed circuit can also be referred to as recycling systems, closed loop systems or intensive recycling systems. The constant reuse of water over and over again is achievable by the addition of oxygen and air to the water supply and the removal of waste products released by the fish. The addition of air limits the production to about 40 kg/m^3 (0.33 lb/gal). The addition of pure oxygen to any system can increase the production to approximately around 120 kg/m^3 (1.0 lb/gal). The removal of solid wastes is usually carried out by mechanical filters in the majority of systems.

This allows for nitrogenous waste such ammonia to oxidise to nitrite and further to nitrate, using the nitrifying bacteria e.g. *Nitrosomonas* (ammonia-oxidizing) and *Nitrobacter* (nitrite-oxidizing) spp. The bacteria are cultured at high densities in biofilters

These bacteria are now cultured at very high densities inside containers called biofilters. The nitrifying bacteria in the biofilter need a surface to attach to such special materials, called media, are wrapped or hung inside the biofilter container to provide additional surface area for large numbers of bacteria to grow on. However, it is also important for the biofilter media to have enough open areas for the water to flow through and wash over the bacteria so that they can 'consume' the inorganic waste and excrete less toxic versions.

2.2.5. Biofloc-based aquaculture

Interest in biofloc-based aquaculture systems has increased over the past 30 years, as these systems can provide relatively bio-secure, more environmentally friendly and financially sustainable aquaculture production. Tilapia and shrimp are well suited to take advantage of the natural productivity of aquaculture systems.

Biofloc technologies can be applied in ponds, tanks, or raceways of different scales. Intensive, biofloc-based production of shrimp is done in lined ponds, from 500 to 20,000 m^2, with a seasonal production of 10 to 20 tons/ha (1 to 2 kg/m^2). These systems are becoming fairly common and are developing rapidly. Production of tilapia using biofloc systems generally produces a much higher biomass than that found in intensive shrimp ponds, of the range of 10 to 30 kg/m^2. A third application of the technology aims at super intensive production of shrimp in tanks or in raceways. Production levels in these systems can reach almost 10 kg/m^2 annually.

Biofloc systems are based on the concept of cultivating a microbial community within the production unit. This microbial community provides important ecosystem services, including recycling waste and providing additional nutrition to the target crop. External inputs include the feed and, in many cases, additional carbon and/or bicarbonate to support the growth of target crop and to meet the needs of the microbial community. The inputs also include energy for additional aeration or oxygenation and mixing to maintain an aerobic microbial consortium suspended. Through good input management, target crop density and the cultivation or oxidation of organic matter during and/or between crops, the producer can achieve a balance, thereby maximizing ecosystem services within the production unit. This can improve cost-effectiveness, stable production conditions and higher overall environmental sustainability of production.

The adoption of low water exchanges and intensive practices for land-based shrimp and tilapia farming has brought several distinct benefits to farmers. Expenses are reduced because the cost of aeration is generally lower than the cost of exchanging water, and contributions from natural productivity can reduce feeding costs. Intensification and reduced water use can minimize land and water costs. For marine shrimp, reduced dependence on water exchange can offer production opportunities in areas far from sensitive and costly coastal lands. Operations are environmentally sustainable because water use and effluents are reduced while making it possible to intensify production, thus reducing the ecological footprint per kg of product produced. Health is improved by improving biosecurity and controlling the introduction of pathogens while cultivating a diverse microbial community, which can improve the competitive exclusion of dangerous pathogens.

With increasing consumer demands for high quality tilapia and shrimp products, increasing pressures on producers to reduce production costs and increasing efforts to ensure environmental responsibility, interest in biofloc-based production technologies continues to grow.

2.2.6. Aquaponics

Aquaponic systems are the culturing of terrestrial plants or aquatic autotrophs in conjunction with raising aquatic animals, typically fish. In aquaponic systems the primary production crops are similar to recirculating systems that include secondary production crops minus the soil. The design of recirculating systems incorporates the ability to hold large amounts of fish in small amounts of water by adding treatments to remove any toxic waste that may be present and then reusing the water. The treated water contains nutrients that are nontoxic and organic matter which can be used to the advantage of primary fish production systems or by secondary crops of economic value. If the secondary crops are aquatic, or if terrestrial plants grown in conjunction with fish, this integrated system is referred to as an aquaponic system.

In aquaponic systems, fish excrete waste nitrogen directly into the water through their gills in the form of ammonia. Bacteria convert ammonia to nitrite and then to nitrate. Ammonia is extremely toxic to fish and nitrite is also toxic to them but when converted into harmless nitrate it is the best form of nitrogen for growth of higher plants, such as fruiting vegetables (Figure 11). It is the symbiotic relationship between fish and plants in which fish provide most of the nutrients that plants require, while plants remove nitrates and improve water quality.

Figure 11 An integrated farming system (fish pond-fruit trees) (Nguyen Van Tu).

Aquaponic systems offer several advantages. In aquaponic systems, the plants uptake a substantial percentage of nutrients in discharged water from fish system which can be reused for the primary system and therefore extending water use and reducing organic pollution. In well-designed aquaponic systems, the plants can purify the culture water and therefore eliminating the need for separate and expensive bioflters which are always incorporated in recirculating systems alone. Moreover, the secondary plant crop receives most of its required nutrients at no additional cost (Figure 12). The profitability of recirculating systems can thus be improved substantially with aquaponics, if there is a good market for the vegetable crop. Aquaponics systems also generate savings in several areas of construction and operation by sharing operational and infrastructural costs for pumps, blowers, reservoirs, heaters, and alarm systems.

There are, of course, disadvantages to aquaponic systems. A large ratio of plant surface to fish surface is needed to achieve a balanced system in which nutrient levels stay relatively constant. More skill labours are needed for seeding, transplanting, maintaining, harvesting, and packing plants. Staffs trained on biological control methods are also required for protecting the plants from pests and diseases.

Figure 12 An integrated farming system (fish pond-piggery-planted weed) (Nguyen Van Tu).

Aquaponic systems are very like recirculating systems in design with the inclusion of a hydroponic component. They also in some cases lack a separate biofilter and accessories for fine and dissolved solids removal. The essential elements of an aquaponic system consist of a tank for rearing fish, a component for the removal of settleable and suspended solids, a biofilter, a sump and a hydroponic component. The functions of these elements are as follows:

- Fish rearing tank is the primary production system which its effluent contains organic matters needed to be reduced and removed. Aquaponic systems are appropriate for the majority of freshwater species, which can tolerate crowding, including ornamental fish. It has been seen that some aquaponic systems have used varies species such as largemouth bass, crappies, channel catfish, rainbow trout and Asian sea bass (barramundi), most commercial systems are used for raising tilapia.

- Removal component is to accumulate and thereby to reduce organic matter concentration in the form of settleable and suspended solids. Solid wastes from closed systems that are usually linked to the hydroponic plant production can be applied as a fertilizer for vegetable or flower gardens.

- Biofilter is to remove ammonia and nitrite through nitrification by bio-reactions of bacteria. It can be a rotating biological contactor.

- Hydroponic component is the secondary production system where its plants uptake dissolved nutrients recovering the quality of water. Various vegetables and herbs, such as lettuce, tomatoes, peppers, eggplant, and basil are commonly linked to fish production systems, and do quite well getting nutrients from the fish wastewater.

- Sump is a reservoir to collect treated water, from which the recovered water is pumped back to the fish rearing tank.

The biofiltration and hydroponic components can be combined by using a plant support media (gravel, sand, floating sheets of polystyrene and net pots) and a sufficient area of plant production.

To ensure a profit with aquaponics aquaculture systems the fish rearing part and hydroponic vegetable part must be operated near maximum production capacity on a continuous basis. Three fish-stock management methods can be used to maintain fish biomass close to the system's maximum carrying capacity, (i) the maximum stocking density possible without affecting fish growth, (ii) using space methodically by operating the system at close to carrying capacity therefore maximising its production, (iii) restricting variation in supplementary feed input to the operation as it is a key element in sizing the hydroponic component. The basic methods of fish management are sequential rearing, stock splitting, and multiple rearing units.

2.2.7. Shellfish aquaculture systems

In the open systems category, we have a number of production methods. For bivalves, these include floats, trays and rafts. By placing the animals in the containers, these normally benthic animals can be suspended off of the bottom. This has the advantage not only reducing predation, but also opening up the three dimensions of the water column to production. It also allows them to be suspended at depths where maximum densities of phytoplankton (their main food source) are found

.

In-bottom or on-bottom growout

The simplest method involves spreading the seed on the bottom and letting it grow to market size. For clams and oysters, planting densities can vary from 300 to 1,500 per m^2, but optimal densities should be determined for any given site. In cases where seeds are inexpensive and acceptable mortality rates, this approach is economical and can be very productive; however, most sites will experience staggering predation mortality.

Rack and bag (subtidal or intertidal)

Various rack-and-bag systems are commonly used for both nursery and grow-out, with the only real difference being that larger shellfish can be grown in larger mesh bags. These bags can be placed on the bottom or kept off the bottom on trestles or in cages and racks; they can be used in subtidal or intertidal locations. Anything the grower can do to improve the flow of water through the mesh will increase the flow of seston, resulting in faster growth, less stress and a better condition index. Larger meshes take longer to clog and will have less resistance to flow, so producers generally use larger meshes which will retain seeds and protect them from predators.

Suspended gear (fixed or floating): Taylor floats and lantern nets

Moving the equipment higher up in the water column generally ensures better current flow, higher phytoplankton concentrations and warmer water, all of which promote faster growth. Many producers use trestles or tables to hold their bags off the bottom of the intertidal zone where they are exposed during part of the tidal cycle. Since animals hanging from floats or rafts are capable of continuous feeding, floating devices are perhaps the best of all worlds for shellfish. Suspended gear allows producers to use areas where benthic conditions may not be suitable for bottom culture while keeping shellfish high in the water column and allowing them to feed continuously.

2.3. Selecting a system

Ecological aquaculture is an alternative model that uses ecological principles and ecosystems thinking as a fundamental organizing paradigm for the development of aquaculture. Ecological aquaculture incorporates - from the start - the principles of natural and social ecology, community development planning and concerns about the broader social, economic and environmental contexts of aquaculture. Ecological aquaculture plans for both economic and social benefit.

An ecological classification of aquaculture systems is given in Table 1. Such aquaculture taxonomies are absolutely necessary so that professionals can develop a more common language when talking about "aquaculture" and its environmental and social impacts potential.

Aquaculture is not a uniform "industry" or a standard set of practices that are easy to classify, codify, label or regulate. It is very important to always define the structure, functions and hierarchical placement of an aquaculture system before addressing its social and environmental links and impacts. Table 2 is an attempt to develop a better classification system for socio-ecological systems for the wide variety of aquaculture ecosystems.

Table 1 Ecological Classification of Aquaculture Systems including A) Biophysical Systems and B) Social-Ecological System Types (taken from Costa-Pierce, 2015)

A) Biophysical System Types	*Functional Attributes*	
Levels of Systems Integration	☐ Stand Alone as Aquaculture ☐ Integrated with Fisheries or Agriculture	
Units	☐ Ponds ☐ Tanks ☐ Cages: Bottom ☐ Net Pens: Fixed ☐ Ropes, Lines, Socks	☐ Raceways ☐ Cages: Floating ☐ Rafts: Nets ☐ Rafts: Ropes
Environmental Location	☐ Outdoor: Natural ☐ Indoor	☐ Outdoor: Artificial
Water Salinities	☐ Fresh water ☐ Saltwater (also called "mariculture")	☐ Brackish water
Water Flow	☐ Running Water (lotic) ☐ Standing Water (lentic) ☐ Standing Water with Flushing	
Water Treatment	☐ Open, Flow-through ☐ Closed, Full Recirculation ☐ Semi-closed, Partial Recirculation	
Feeding Strategies	☐ Continuous ☐ Natural	☐ Scheduled
Feed Qualities	☐ Complete ☐ Natural	☐ Supplemental
Seed/Fry Sources	☐ Nature ☐ Wild Capture of Broodstock	☐ Hatcheries
Species Natural Food Habits	☐ Carnivorous ☐ Omnivorous	☐ Herbivorous ☐ Opportunistic
Species Stocking Strategies	☐ Monoculture ☐ Janitorial Polyculture	☐ Polyculture
Species Temperature Tolerances	☐ Coldwater ☐ Warm water	☐ Stenothermal ☐ Eurythermal
Species Salinity Tolerances	☐ Marine ☐ Euryhaline	☐ Freshwater ☐ Stenohaline
B) Social-Ecological System Types	*Kinds*	
Management (Stocking, Economic) Intensities	☐ Intensive ☐ Extensive	☐ Semi-Intensive
Marketing Channels	☐ Human Food: Local ☐ Human Food: Export ☐ Recreation ☐ Display	☐ Tourism

Table 2 A natural and social ecological classification of aquaculture ecosystems (adapted from Costa-Pierce, 2003)

System Classification	Solar aquaculture	Smallholder aquaculture	Semi-intensive aquaculture	Intensive aquaculture	Intensive industrial aquaculture
Feed	Natural foods	Low quality supplemental feeds, fertilizers	High quality supplemental feeds, fertilizers	Complete feeds	Complete, high protein feeds
Cultured species	Plants, shellfish, fish	Tilapias, carps, crustaceans	Crustaceans, fish	Marine fish, crustaceans	Marine fish, crustaceans
System	In nature, in large ponds	Ponds, tanks	Ponds, tanks	Tanks, pens, raceways	Tanks, pens, raceways
Business type	Families, small businesses	Families, small businesses	Families, small to medium-scale national businesses	Large, regional and national businesses	Multi-national corporations

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3. Aquaculture production in Asian countries

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3.1 Current status of production

3.1.1 World aquaculture

Scale of production

Year on year aquaculture has continued to increase its contribution to global seafood production. Global fish production reached almost 171 million tonnes (MT) in 2016, of which aquaculture contributed 46.8 %, up from 25.7 % in 2000 (Figure 13). The total first sale value of fisheries and aquaculture production in 2016 was estimated at USD 362 billion, of which USD 232 billion was from aquaculture production (64.1 %). Although, annual growth rates, (excluding aquatic plants), have slowed down from 11.3 % in the 1980s, to 10 % in the 1990s and 5.8 % during the period 2000–2016; aquaculture continues to grow faster than other major food production sectors. The contribution of aquaculture to the fish supplied for human consumption has been continuing to display an impressive growth since the late 1980s.

Global aquaculture production in 2016 included 80 MT of fish, 30.1 MT of aquatic plants, as well as 37,900 tonnes of non-food products. Farmed fish production included 54.1 million tonnes of finfish (valued at USD 138.5 billion), 17.1 MT of molluscs (USD 29.2 billion), 7.9 MT of crustaceans (USD 57.1 billion) and 938,500 tonnes of other aquatic animals (USD 6.8 billion), such as turtles, sea cucumbers, sea urchins, frogs and edible jellyfish.

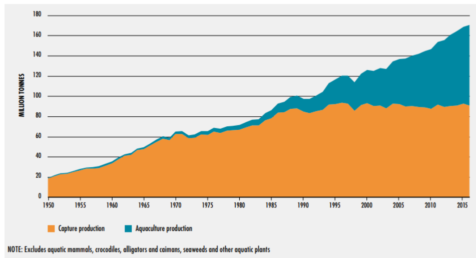


Figure 13 World capture fisheries & aquaculture production (FAO, 2018).

Socio-economic development

The aquaculture sector contributes to food security and nutrition directly through domestic consumption. Indirectly, commercial aquaculture can generate household income and national economic growth though employment and exports of produce. In 2016, about 88% of the 171 MT of total fish production or over 151 MT were utilized for direct human consumption. Fish consumption (in per capita terms) grew from 9 kg in 1961 to 20.2 kg in 2015. Fish subsequently accounted for about 17% of animal protein consumed by the global population. Many millions of people around the world find a source of income and livelihood in the fisheries and aquaculture sectors. The proportion of those employed in aquaculture correspondingly increased from 17% in 1990 to 32% in 2016. In 2016, 85% of the global population engaged in the fisheries and aquaculture sectors was in

Asia with employment in aquaculture primarily concentrated in Asia (96% of all aquaculture engagement). About 35% of global fish production entered international trade in various forms for human consumption or non-edible purposes, with an export value of USD 143 billion in 2016. The major Asian exporters were China, India, Vietnam and Thailand, while the major importers were developed countries (except for China) (Table 3).

Aquaculture systems

The latest FAO global aquaculture production statistics recorded 608 'species items' under ASFIS, (Aquatic Sciences and Fisheries Information System), a total list of all aquatic species that have been farmed in global aquaculture during the period from 1950 to 2017. Among them, 424 'species items' were farmed in 2017 (compared to 254 'species items' in 1990).

In broad terms, aquaculture production systems used for producing aquatic animals and plants can be divided into feed-dependent systems or fed aquaculture (e.g. finfish and crustaceans) and non-fed aquaculture systems where culture is predominately dependent on the natural environment for food, e.g. aquatic plants and molluscs.

Aquatic animals and plants are cultured in diverse farming systems, ranging from low-input extensive to high-input intensive systems, including:

- Water-based systems
  (cages and pens, inshore/offshore).
- Land-based systems
  (rainfed ponds, irrigated or flow-through systems, tanks and raceways).
- Recycling systems
  (high control enclosed systems, more open pond-based recirculation).
- Integrated farming systems
  (e.g. livestock-fish, agriculture and fish dual use aquaculture and irrigation ponds).

Earthen ponds remain the most commonly used type of facility for inland aquaculture production, although raceway tanks, above-ground tanks, pens and cages are also widely used where local conditions allow. Rice–fish culture remains important in areas where it is traditional, but it is also expanding rapidly, especially in Asia.

In 2016, inland aquaculture was the source of 51.4 MT of food fish, or 64.2% of the world's farmed food fish production, as compared with 57.9% in 2000. Finfish farming still dominates inland aquaculture, accounting for 92.5% (47.5 MT) of total production from inland aquaculture. However, this proportion was down from 97.2% in 2000, reflecting a relatively strong growth in the farming of other species groups, particularly crustaceans (including shrimps, crayfish and crabs) in inland aquaculture in Asia. Also, 28.7 MT of food fish production was from mariculture and coastal aquaculture combined in 2016. In sharp contrast to the dominance of finfish in inland aquaculture, shelled molluscs (16.9 MT) constituted 58.8% of the combined production of marine and coastal aquaculture. Finfish (6.6 MT) and crustaceans (4.8 MT) together were responsible for 39.9%.

In 2016 the total finfish production of 54.091 MT, was largely comprised of Chinese carps (grass carp *Ctenopharyngodon idellus*, silver carp *Hypophthalmichthys molitrix* and bighead carp *Hypophthalmichthys nobilis*) and tilapias (*Oreochromis* (=*Tilapia*) spp.), followed by Indian major carps (Catla *Catla catla* and roho labeo *Labeo rohita*), common carp (*Cyprinus carpio*), *Carassius* spp., Atlantic salmon (*Salmo salar*), *Pangasius* spp., milkfish (*Chanos*

Table 3 Top ten exporters and importers of fish and fish products (taken from FAO, 2018)

Country	2006		2016	
	Value (million USD)	Share (%)	Value (million USD)	Share (%)
Exporters				
China	8 968	10.4	20 131	14.1
Norway	5 503	6.4	10 770	7.6
Viet Nam	3 372	3.9	7 320	5.1
Thailand	5 267	6.1	5 893	4.1
United States of America	4 143	4.8	5 812	4.1
India	1 763	2.0	5 546	3.9
Chile	3 557	4.1	5 143	3.6
Canada	3 660	4.2	5 004	3.5
Denmark	3 987	4.6	4 696	3.3
Sweden	1 551	1.8	4 418	3.1
Top ten subtotal	**41 771**	**48.4**	**74 734**	**52.4**
Rest of world total	**44 523**	**51.6**	**67 796**	**47.6**
World total	**86 293**	**100.0**	**142 530**	**100.0**
Importers				
United States of America	14 058	15.5	20 547	15.1
Japan	13 971	15.4	13 878	10.2
China	4 126	4.5	8 783	6.5
Spain	6 359	7.0	7 108	5.2
France	5 069	5.6	6 177	4.6
Germany	4 717	5.2	6 153	4.5
Italy	3 739	4.1	5 601	4.1
Sweden	2 028	2.2	5 187	3.8
Republic of Korea	2 753	3.0	4 604	3.4
United Kingdom	3 714	4.1	4 210	3.1
Top ten subtotal	**60 533**	**66.6**	**82 250**	**60.7**
Rest of world total	**30 338**	**33.4**	**52 787**	**39.3**
World total	**90 871**	**100.0**	**135 037**	**100.0**

[a] APR: average annual percentage growth rate for 2006–2016.

chanos) and other finfishes(Figure 14). The whiteleg shrimp (*Penaeus vannamei*) contributed over 50% of the total crustacean production (7.862 MT, 2016). Other species to contribute included the red swamp crawfish (*Procambarus clarkii*), the Chinese mitten crab (*Eriocheir sinensis*), the giant tiger shrimp (*Penaeus monodon*), the oriental river prawn (*Macrobrachium nipponense*) and the giant river prawn (*Macrobrachium rosenbergii*) (Figure 15). Molluscan production (17.139 MT) in 2016, saw cupped oysters (*Crassostrea* spp.) and the Japanese carpet shell (*Ruditapes philippinarum*) contribute >50%, with scallops nei (Pectinidae), mussels (Mytilidae), constricted tagelus (*Sinonovacula constricta*), blood cockles (*Anadara granosa*) and other molluscs making up the balance (Figure 16).

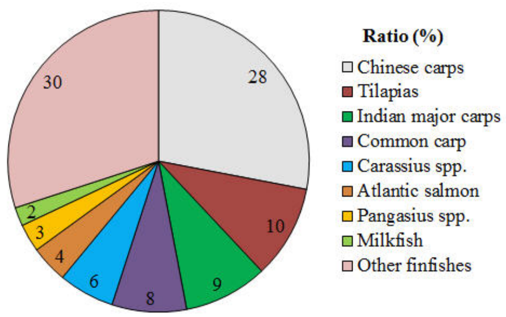


Figure 14 Contribution of fish groups to total finfish production in 2016 (Source: FAO, 2018)

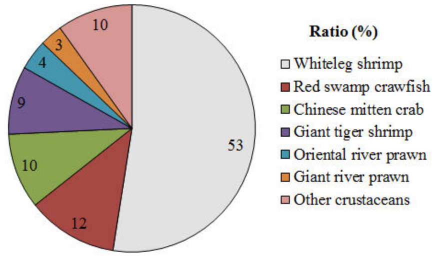


Figure 15 Contribution of crustacean groups to total crustacean production in 2016 (Source: FAO, 2018)

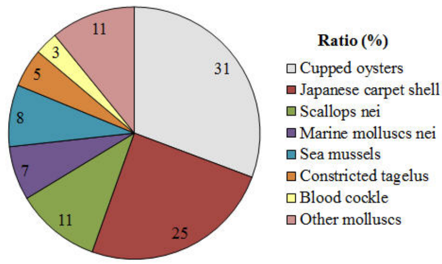


Figure 16 Contribution of molluscan groups to total mollusc production in 2016 (Source: FAO, 2018)

3.1.2. Asian aquaculture

Scale of production

Aquaculture has had a long history in Asia. In many countries, such as China, Cambodia, Lao PDR, Myanmar, Thailand, Vietnam, India and Bangladesh, it is likely that aquaculture originated inland, as part of or as an extension of the rice paddies, while brackish water aquaculture is thought to have started later. This is reflected in the importance and dominance of freshwater aquaculture in these countries. In fact, the development of brackish water aquaculture in the region resulted in response to the shrimp fever, which gripped the region (Thailand and China) in the 1980s and the mid-1990s in Vietnam. In contrast, Indonesia and the

Philippines have had a well-developed brackish water aquaculture industry for centuries with milkfish as the major species cultured in coastal ponds before the development of marine shrimp culture.

Asian countries are the largest fish producers, accounted for approximately 89% of the world aquaculture production for over two decades. At the regional level, the share of aquaculture in Asian fish production (excluding China) increased from 19.3% in 2000 to 40.6% in 2016. The major fish producer of the region is China with 61.5% of world total in 2016. The remaining production is attributed to India (7.1%), Indonesia (6.2%), Vietnam (4.5%), Bangladesh (2.8%), Myanmar, Thailand and the Philippines (Table 4).

Driving forces of production

In many parts of the world, the development of aquaculture was driven by factors such as the increasing demand for aquaculture products as a result of the decrease in the supply from capture fisheries. In addition, scientific breakthroughs in production technologies and governments' will and determination to establish enabling policies and legal and regulatory frameworks for aquaculture have all attributed to the growth. A substantial increase in the production of any one individual aquaculture species usually results in a significant drop in the price of that species. For the production to be profitable, technological innovations must take place to increase productivity and reduce production cost. Therefore, the driving forces for aquaculture growth are reflected in the needs of industry for growth in productivity, profitability and the production of consistent-quality products.

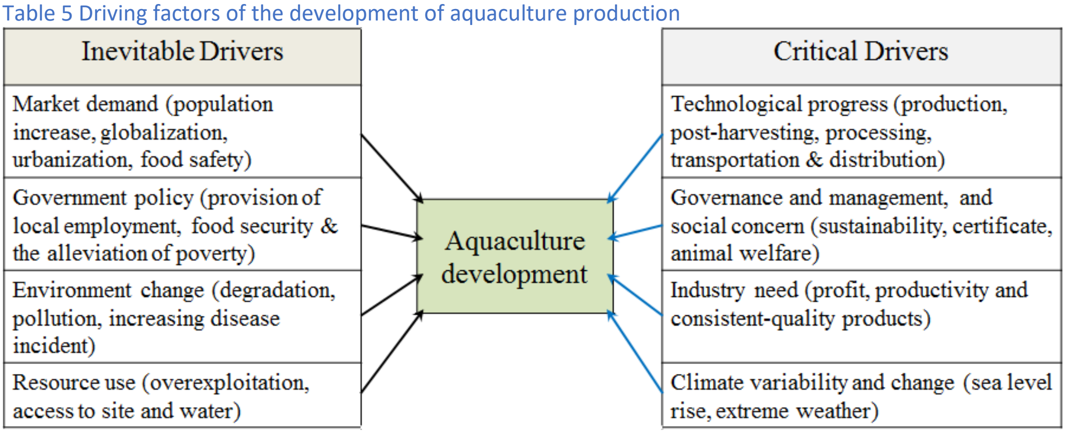
Table 4 Aquaculture food fish production by major Asian producers (FAO, 2018)

Region/selected countries	1995	2000	2005	2010	2015	2016
Asia	21 678	28 423	39 188	52 452	67 881	71 546
	88.9%	*87.7%*	*88.5%*	*89.0%*	*89.3%*	*89.4%*
China (mainland)	15 856	21 522	28 121	36 734	47 053	49 244
	65.0%	*66.4%*	*63.5%*	*62.3%*	*61.9%*	*61.5%*
India	1 659	1 943	2 967	3 786	5 260	5 700
	6.8%	*6.0%*	*6.7%*	*6.4%*	*6.9%*	*7.1%*
Indonesia	641	789	1 197	2 305	4 343	4 950
	2.6%	*2.4%*	*2.7%*	*3.9%*	*5.7%*	*6.2%*
Viet Nam	381	499	1 437	2 683	3 438	3 625
	1.6%	*1.5%*	*3.2%*	*4.6%*	*4.5%*	*4.5%*
Bangladesh	317	657	882	1 309	2 060	2 204
	1.3%	*2.0%*	*2.0%*	*2.2%*	*2.7%*	*2.8%*
Rest of Asia	2 824	3 014	4 584	5 636	5 726	5 824
	11.6%	*9.3%*	*10.4%*	*9.6%*	*7.5%*	*7.3%*

In general, the factors driving the development of aquaculture production can be grouped into either inevitable or critical. Among them, the rising global demand for seafood is the most inevitable driver and technological progress is the most critical one (Table 5).

The driver of increased market demand will be a combination of increasing population, rising incomes and urbanization, linked with the expansion of fish production, improved distribution channels, higher food safety requirement and globalization.

Table 5 Driving factors of the development of aquaculture production



Technological progress is evident in the areas of production (method and management), post-harvest handling, processing, preservation, packaging, storage and transportation. The aquaculture industry was quick to adopt and apply these advances increasing further the development of aquaculture.

History of Aquaculture systems

Polyculture in integrated freshwater aquaculture systems in Asia, and in particularly China, has traditionally been practised for more than 1000 years. Even today, polyculture comprises a major component of Asian aquaculture. A good example of polyculture includes the pond rearing of different carp species (e.g. carnivore, omnivore and herbivore) that utilize different nutrients. This balance keeps the pond in a satisfactory ecological condition. Cage aquaculture is thought to date back to, as early as, the 1200s in some areas of Asia. Polyculture in earthen brackish water ponds has also been practised for a very long time, with extensive polyculture systems for shrimp, fish and agriculture plants found today largely in China, Indonesia, India, the Philippines, Taiwan Province of China, Thailand, Japan and more recently in Vietnam. Pond aquaculture in mangroves, where the forest is either part of a polyculture system or is used as a filter in sequential culturing, has been practised for centuries in Indonesia, China, and Hong Kong Special Administrative Region. This practice has also more recently been developed in the Philippines, Malaysia, Vietnam, and

Thailand. Traditional integrated open water mariculture systems, located principally in China, Japan, and South Korea have a similar long history. These operations have consisted of fish net pens, shellfish and seaweed placed next to each other in bays and lagoons. In Asia, most of the aquaculture production results from small-scale family-owned enterprises generally integrated with other agriculture activities.

In recent decades an aquaculture revolution has taken place with the development of semi-intensive and intensive production systems, as a result of innovative production technology. Extensive traditional sustainable farming systems, which use local resources and supply food fish to local markets, are increasingly being replaced by more intensified systems which use imported resources (feed, energy). The intensification of aquaculture systems has resulted from the progress in a number of areas including reproductive control and seed supply, nutrition and feed production, health management and disease control, farming practices and management. The application of technological advances has been shaping aquaculture production systems as seen in shrimp production in Asia (Figure 17) and striped catfish production in Vietnam (Figure 18).

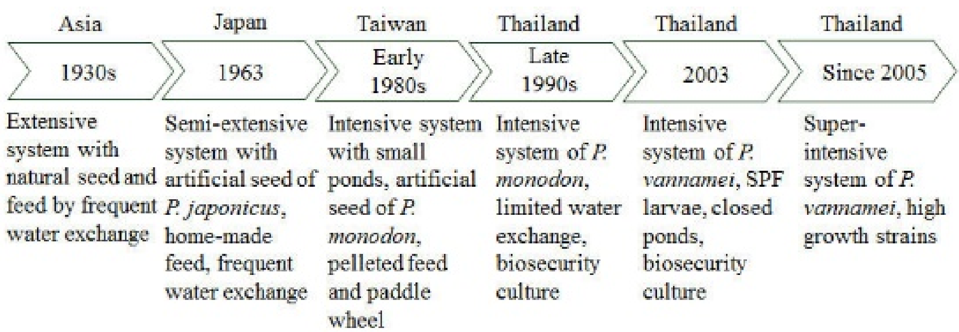


Figure 17 Lifetime of development of shrimp production systems in Asia

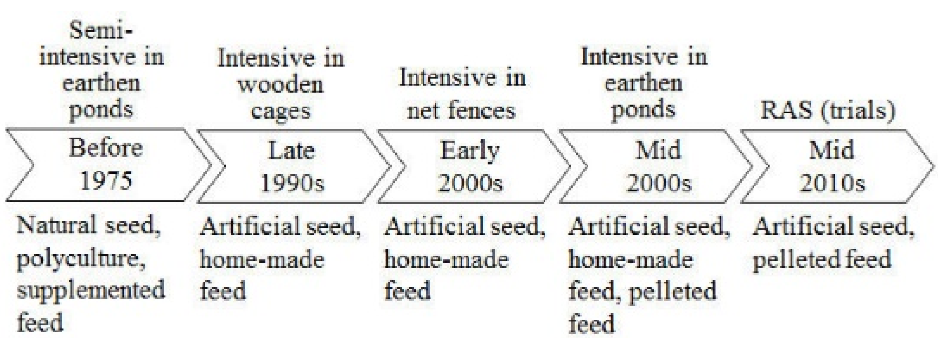


Figure 18 Lifetime of development of striped catfish production systems in Vietnam

3.2. Aquaculture - Asian countries

3.2.1. Vietnam

History of aquaculture

Aquaculture has been practiced in Vietnam since the 1960s. The aquaculture sector went through three main stages in the development: an initial period from 1960 until reunification of the country in 1975, a second from 1975 to renovation policy in 1986 and a third from 1986 until the present day. In the initial period, aquaculture was predominantly fish culture in freshwater ponds. During the Vietnam war (1963-1975), the aquaculture sector was operated by cooperatives and state-run enterprises in the northern part of the country and by small farmers in the south to provide food for people. After 1975, aquaculture was promoted throughout the country because of its importance in providing nutritious food and generating income for people. Several aquaculture farming systems were encouraged such as fish culture in earthen pond in VAC systems (i.e. Vuon, Ao, Chuong which translates garden/pond/livestock pen), rice-cum-fish (integrating rice farming with fish production), fish culture in river cages and lakes, and extensive shrimp culture in mangrove forests. During the third stage, aquaculture turned its focus on increasing aquaculture exports through increasing production and development. Aquaculture was encouraged throughout the country from small-scale households to private and state-run enterprises and in all environments from freshwater, brackish water to marine. Since the 1990s, the rise of shrimp farming for export has been an important breakthrough and the primary species being exported. Subsequently in the following decade, striped catfish became an important freshwater export species and is now the second main species being exported after shrimp. The area of brackish water, particularly under aquaculture farming, has increased (Figure 19).

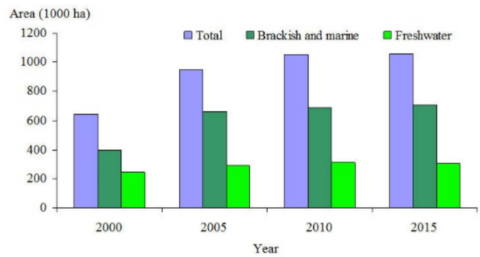


Figure 19 Aquaculture area in hectares by year (Source: GSO, 2016)

In addition to an increase in the culture area, the aquaculture sector has also diversified in terms of cultured species and systems, and levels of intensification (stocking density and inputs). All of these have resulted in an increase in yields and outputs. Subsequently, aquaculture production has continuously increased at an average growth rate of 12.77% per annum. Since 2007, aquaculture production for the first time exceeded that of capture fisheries (Figure 20) and in 2015, aquaculture accounted for 54% (3.532 MT) of the total fisheries outputs.

Aquaculture has gradually changed over the years from a self-sufficient sector into one of Vietnam's key commodities and today continues to play an important role in the nation's economy. Aquaculture plays a very important role in the economic restructure strategy in agriculture as well as the implementation of hunger alleviation and in the poverty reduction programme in different regions within the country.

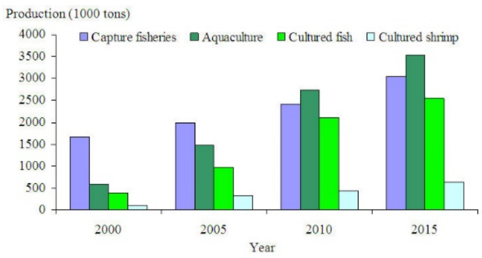


Figure 20 Aquaculture production of Vietnam by year (Source: GSO, 2016)

Current status

Aquaculture species

A wide range of aquatic species have been utilised in aquaculture in Vietnam. In addition to indigenous animals, many fish and shrimp species potentially farmed in freshwater, brackish water and marine environments have been imported to diversify aquaculture products and avoid issues with disease recorded from the current species cultured. Species are cultured in mono or polyculture systems and products are supplied to both domestic and export markets (Table 6).

In general, shrimp dominate the area covered by aquaculture while fish species formed the major aquaculture output (Figure 21 and Figure 22). In freshwater aquaculture, carp were the dominant species farmed by area, but striped catfish was the main species in production, accounting for 44.27% and 31.79% of total fish and aquaculture outputs, respectively. Carp was supplied as food fish to domestic consumers, while catfish was mainly provided as a raw material for export. In brackish water, the black tiger and white leg shrimps dominated both farmed area (93.88%) and production (93.54% of total shrimp and prawn outputs) and supplied both domestic and international markets. Lobster and clam were the most commonly produced of the marine species.

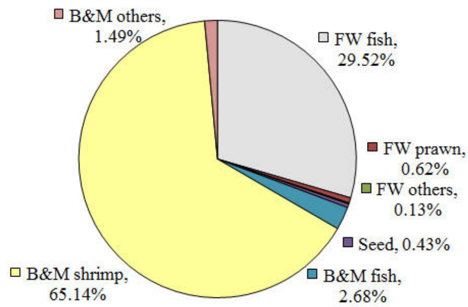


Figure 21 Ratios of aquaculture area shared by commodities in 2015 (compiled from GSO data). Note: FW: freshwater; B: brackish water; M: marine

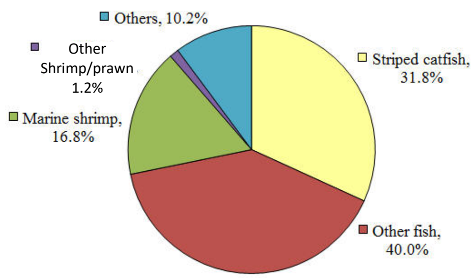


Figure 22 Ratios of aquaculture outputs contributed by commodities in 2015 (compiled from data of GSO).

Marine aquaculture, including areas of bays, coastal tidal flats, and parts of islands and open seas, has seen an expansion year on year in Vietnam (Table 7). The total potential area for marine and island aquaculture is about 244,190 ha, in which 153,300 ha of coastal tidal area (accounting 62%), 79,790 ha of bays, lagoons and islands (33%) and 11,100 ha of open sea (5%).

Table 6 Sources, farming environments, culture systems and markets of popular aquaculture species of Vietnam

Species	**Source**		**Environment**		**System**		**Market**	
	In	**Im**	**F**	**B&M**	**M**	**P**	**D**	**E**
Fishes								
Common carp (*Cyprinus carpio*)	x	x	x		x	x	x	
Silver carp (*Hypophthalmichthys molitrix*)		x	x			x	x	
Bighead carp (*Aristichthys nobilis*)		x	x			x	x	
Grass carp (*Ctenopharyngodon idellus*)		x	x			x	x	
Rohu (*Labeo rohita*)		x	x			x	x	
Mrigal (*Cirrhinus mrigala*)		x	x			x	x	
Catla (*Catla catla*)		x	x			x	x	
Tra catfish (*Pangasianodon hypophthalmus)*	x		x		x		x	x
Basa catfish (*Pangasius bocourti*)	x		x		x		x	x
African walking catfish (*Clarias gariepinus*)		x	x		x		x	
Hybrid walking catfish (*C. gariepinus* x *C. macrocephalus*)			x		x		x	
Nile tilapia (*Oreochromis niloticus*)		x	x	x	x	x	x	x
Red tilapia (*O. niloticus* x *O. mossambicus)*		x	x		x		x	x
Giant gourami (*Osphronemus gouramy*)		x	x			x	x	
Sand goby (*Oxyeleotris marmoratus*)	x		x		x		x	x
Asian redtail catfish (*Hemibagrus wyckioides*)	x		x		x		x	
Climbing perch (*Anabas testudineus*)	x		x		x		x	
Striped snakehead fish (*Channa striatus*)	x		x		x		x	
Cobia (*Rachycentron canadum*)		x		x	x		x	
Rainbow trout (*Oncorhynchus mykiss*)		x	x		x		x	
Asian seabass (*Lates calcarifer*)	x			x	x		x	
Grouper (*Epinephelus* spp.)	x	x		x	x		x	x
Eel (*Anguilla bicolor & A. marmoratus*)	x		x		x		x	
Crustaceans								
Freshwater giant prawn (*Macrobrachium rosenbergii*)	x		x		x		x	x
Black tiger shrimp (*Penaeus monodon*)	x			x	x	x	x	x
White leg shrimp (*Litopenaeus vannamei*)		x		x	x	x	x	x
Spiny lobster (*Panulirus ornatus*)	x			x	x			x
Mud crab (*Scylla paramamosain*)	x			x	x		x	
Bivalve Molluscs								
Clam (*Meretrix lyrata & M. meretrix*)	x			x	x		x	x
Blood cockle (*Anadara granosa*)	x			x	x		x	
Oyster *(Crassostrea* spp.*)*	x			x	x		x	
Seaweed								
Gracilaria seaweed (*Gracilaria verrucosa*)	x			x	x		x	

Note: In: indigenous, Im: imported, F: Freshwater, B&M: brackish water and marine, M: monoculture, P: polyculture, D: domestic, E: export

Table 7 The area and production of marine aquaculture of Vietnam from 2010 to 2015 (Source DoF, 2016a).

Items	2010	2012	2014	2015
Total marine cultured area (ha)	38,880	39,110	39,320	40,102
Total marine cultured production (tonne)	156,681	200,175	282,188	308,587
Marine fish (tonne)	15,751	34,413	34,026	30,550
Molluscs (tonne)	133,534	158,277	239,473	269,161
Crustaceans (tonne)	7,396	7,485	8,689	8,876

Production systems

Freshwater aquaculture

a. Brood-stock and fingerlings

There are two main steps involved in the production of fish seed namely, brood-stock maintenance and the production of fry (i.e. hatchery), followed by the growth of fry to fingerling (i.e. nursery). This two-step system is applied for almost all cultured fish with the exception of tilapia.

A hatchery can range from an operation in the 'backyard' to commercial-scale operations equipped with earthen ponds for brood-stock maintenance, hatching jars, concrete and/or composite tanks for holding fry. Fry production is completed through breeder-induced spawning with hormone treatment and subsequent artificial insemination. The hatchlings are then kept in the tanks without feeding until sold to nursing farmers.

Although some hatcheries also have nursery facilities most of the rearing from fry to fingerling is carried out in specialized farms. Here the fry are nursed in an earthen pond and fed with live, supplementary and industrial feeds.

Seed production hatcheries of striped catfish are largely located in Dong Thap and An Giang provinces while fry to fingerling nursery farms can be found in Dong Thap, An Giang and Can Tho provinces. In 2016, there were 108 hatcheries and 1,856 nurseries with a total pond area of 1,500 ha in the Mekong River Delta, where the seed production was about 16.5 billion fry.

Tilapia seed production is practiced in earthen ponds. At the beginning of the production cycle, spawning ponds are prepared by draining, liming, drying, refilling and fertilizing. The breeders ready to spawn are stocked in the ponds when they become green. After 15-20 days after stocking, the breeders are moved to similarly prepared spawning ponds by seining. Tilapia seed is either then harvested for selling or remained within the ponds where the nursing will continue. Tien Giang province is the largest area of tilapia seed production in the MRD. However, high quality tilapia seed for intensive culture systems is regularly imported from China. The harvested fingerlings are then sold to the farmers who own facilities for keeping seed or to grow-out farmers.

The hatcheries of freshwater giant prawn seed production are similarly equipped to fish hatcheries. Females incubating eggs in their abdomen space are collected from the wild or grow-out ponds and are subsequently kept in spawning tanks containing diluted sea water (12-15 PSU). The females are moved out of the tanks once they have released the larvae. The larvae are nursed in the same tanks until they reach the postlarvae (PL) stage. There are several larval culture systems including: closed, clear-water, and green-water. The postlarvae are first gradually acclimatised to freshwater and then shifted to be nursed in freshwater earthen ponds until they reach the juvenile stage.

b. Grow-out

Although some new grow-out systems such as RAS (for eel and tra catfish culture) and flow-through ponds (for rainbow trout culture) have been tried, most food fish are reared in an earthen pond and cage culture systems.

b1. Earthen pond culture

Earthen pond production systems involve the culture of both single species culture (monoculture system) and multiple species (polyculture system). The culture of multiple species involves stocking different fish species that both eat different types of feed and live and occupy different layers/depths within the water. Therefore, the space and feed can be utilized efficiently in this polyculture system. This system is normally used in both extensive and semi-intensive culture.

i. Polyculture system

Polyculture systems have been traditionally practiced in Vietnam at both a small-scale and a semi-intensive level. The cultured species are often specific to different geographical regions. In the northern and central highland of Vietnam, common carp, Chinese carps (silver carp, bighead carp and grass carp) and Indian major carps are the main species cultured. In southern Vietnam, tilapia is the main species combined with common carp, Indian major carps and indigenous species (striped catfish, gourami). In northern and central highland regions, organic manure is commonly applied to develop natural feed (phytoplankton plus zooplankton and detritus) for cultured fish. In general, fish are fed with agricultural by-products and home-made feed and less often with industrial feed. With a density of 3-5 fish per square meter applied, the yield of the system can potentially be 3-10 tonnes per hectare. The harvested fish is supplied to local markets through a middleman or the farmers themselves.

ii. Monoculture system

Monoculture systems have recently been developed in Vietnam, particularly in the Red river (RRD) and Mekong river (MRD) deltas. The main species cultured in the RRD is tilapia, while the MRD has a more diverse range of species cultured including the striped (tra) catfish, tilapia, hybrid walking catfish, climbing perch, snakehead fish and freshwater giant prawn. This results in a high intensity system in terms of stocking density, feeding and management. The cultured fish are supplied with either home-made feed or more commonly with industrial feed. The yield from this system is high, particularly for snakehead fish and striped catfish. The harvested product is supplied as food fish to domestic markets and as raw materials for processing and export through wholesalers and middlemen

b2. Cage culture

Historically cages were originally constructed of wood. Cage culture with basa catfish was a traditional system in the Mekong River delta. The practice of striped (tra) catfish culture in wooden cages was tumultuously developed in the late 1990s when the fish became an export commodity. The system was shifted to tilapia culture when striped catfish moved to ponds in 2000s.

Tilapia culture in cages has subsequently reduced gradually due to high cost of the initial investment and the limited markets for the product. Now, cage culture is mainly practiced with red tilapia, common carp and Asian redtail catfish in nylon nets in rivers, reservoirs and lakes. The cultured fish is fed with home-made feed or more commonly with industrial feed. The harvested fish is supplied to domestic markets through middlemen and wholesalers.

Marine and brackish water

Brackish water aquaculture is generally referred to the culture of crustaceans such as shrimp and mud crab and Asian seabass in coastal earthen ponds. While traditionally, marine aquaculture is concentrated on the production of molluscs and seaweeds; however, it is now expanded to include high-value finfish such as cobia and groupers, and shellfish such as lobsters.

a. Seed production

The first hatchery to successfully produce seed from the black tiger shrimp was built in Khanh Hoa province of the south-central coastline region between 1984 and 1985. This initiated the marine shrimp farming industry, with breeders collected from the wild. When the industry was further developed, seed production areas moved to the southern provinces, such as Ninh Thuan and Binh Thuan due to cheaper land, better water sources and attractive investment policies. In 2008, permission was granted for the white leg shrimp to be farmed throughout the whole country. Since then, many hatcheries shifted their focus to produce the seed of this species from imported specific pathogen free (SPF) breeders. The development of shrimp farming in the MRD has stimulated the building of more shrimp hatcheries in regional provinces such as Soc Trang, Bac Lieu, Ca Mau and Kien Giang.

Most hatcheries are well equipped with specific tanks (i.e. spawning, egg hatching, larval rearing and nursery maintenance tanks) and facilities for water treatment and environmental management. Screens are normally used to control light intensity from the sun and, hence, water temperature. Hatchery tanks are built of composite or concrete, often lined with epoxy polyester paint. The tanks vary in shapes (e.g. round, square and rectangular with rounded corners) and sizes (10-50 m^3).

Gravid females are stocked at a rate of 1-1.5 individuals per cubic meter of water. After spawning, the females are removed. The eggs in the tanks are allowed to hatch and larval rearing commences. Spawning, hatching, larval rearing and nursery rearing can be done in the same or separate tanks of different volumes. Diatoms, *Artemia* and artificial larval pellets are used for larval rearing. Water changes may start during the late protozea 3 stage and onwards. Siphoning of uneaten feed and organic debris is carried out simultaneously with water exchange. Harvesting is done by draining the tanks and trapping the postlarvae into filter screen boxes or fine-mesh bags submerged in collecting basins. Postlarvae are then packed in oxygenated plastic bags for distribution to farms.

In 2017, there were 1,863 facilities producing marine shrimp seed, in which 1,297 focused on the black tiger shrimp and 566 on the white leg shrimp. The total seed production in 2016 was 104.4 billion postlarvae, of which 24.1 billion black tiger shrimp and 80.3 billion white leg shrimp. Central coastline provinces contributed 64.5% of the total shrimp seed production in 2016. The top five shrimp seed companies in 2013 were Vietnam CP, Uni-President, Viet-Uc, Thong Thuan and Thien Phu.

In 2015, there were 32 facilities producing marine fish seed. The annual seed production was about 30 million fingerlings of cobia, grouper, red drum, pomfret, etc. The main area of marine fish seed production is the north coastline region (Quang Ninh, Hai Phong) and the south-central coastline region (Khanh Hoa).

b. Grow-out

Brackish water aquaculture is mainly focused on shrimp farming in land-based systems while marine aquaculture is largely water-based systems.

b1. Land-based systems

i. Integrated mangrove-shrimp systems

Integrated mangrove-shrimp systems are a traditional form of raising shrimp that are markedly different to other production forms found in the coastal areas of the MRD. On average, each household is allocated about 3-10 ha of mangrove forest land managed by State Forestry Fisheries Enterprises (SFFEs) of which 40-70% of the land area is designated for the recruitment and planting of *Rhizophora* mangrove trees and 30-60% can be used for aquaculture, depending on the farm area. The household invests both money and labour into excavating canals and building embankments that are 5 m wide with one outlet and one inlet sluice gate. These extensive polycultures are characterised by no or low feed inputs, no or low fertilization rates, passive water exchange and low production. The integrated mangrove-shrimp ponds occupy about 50,000 hectares. In Ca Mau province, these farms make up around 15% of the total shrimp farming area but contributes with less than 5% towards the total production. To improve production, hatchery-reared black tiger shrimp (*Panaeus mondon*) PL are frequently stocked at low density (average 13.58 PL/m^2/yr). The total average production is 492 $kg.ha^{-1}.yr^{-1}$, of which 193 kg is cultured shrimp and 153 kg of wild ones (banana shrimp (*P. merguiensis*), Indian shrimp (*P. indicus*), and sand shrimp (*Metapenaeus ensis*), etc).

The simple techniques, low capital investment, low environmental impact, regular harvests, little disease and few economic risks have resulted in this production system and been close to satisfying all the criteria required to be designated as organic. By 2010, around 1,000 integrated mangrove-shrimp farms with a total area of 6,000 ha had been certified as organic by the German organic certification scheme Naturland and audited by other international certification organizations following years.

ii. Improved extensive shrimp farming systems

The improved extensive shrimp farming systems occupy about 330,000 hectares in the MRD. Within this large area, aquatic plants *(Scirpus littoralis* and *Typha* spp), seaweeds *(Enteromorpha, Gracilaria, Cladophora* and *Chaetomorpha)* and/or mangrove trees are allowed to develop naturally or are planted. These plants are good for the environment and create excellent habitat for shrimp, fish and especially mud crabs. In these systems, wild shrimp, fish and crabs flow into the ponds through tidal water exchange during the full moon and new moon. To improve the harvest, hatchery-reared black tiger shrimp PL are stocked, several times, at low density (average $15.44/m^2/yr$). Mud crabs, blood cockles *(Anadara granosa)* and some brackish water fish are also stocked at low density to make use of the natural food available and to allow for diversification of products and increased income. Almost no supplemental feed is used in these systems. The total production is 432 kg/ha/yr on average, of which 213 kg is cultured shrimp and 95 kg wild shrimp.

To increase shrimp survival rates, production and income from these systems further improvements in farming technology are needed.

iii. Rotated rice-shrimp culture

The rotated rice-shrimp farming systems were developed in 2001 in the MRD when the government re-designated unproductive areas originally planned solely for rice to allow aquaculture to take place also. These systems currently occupy more than 160,000 ha. The black tiger shrimp is cultured in the dry season with brackish water and subsequently rice is cultivated in the rainy season with freshwater. The systems consist of a flat area in the centre surrounded by a deep ditch along the dyke. The stocking density is generally 2-8 $PL.m^{-2}$ depending on the water level, which is between 30 and 80 m. A low stocking density involves a casual feeding routine and simple management techniques, while a high stocking density of shrimp requires more rigorous management of water and feeding. After a period of 3-4 months, the expected yields of 200-300 kg/ha/crop can be obtained for low stocking systems of shrimp and 800-1,500 kg/ha/crop for high stocking system. To improve the harvest, and subsequent income, the freshwater giant prawn (*Macrobrachium rosenbergii*) and the sand goby (*Oxyeleotris marmoratus*) are also normally stocked at a low density with casual feeding.

iv. Intensive shrimp farming systems

Intensive farming with black tiger shrimp was developed in the middle of 1990s in south central coastline provinces. However, the MRD has become the biggest shrimp production area due to its favourable conditions for shrimp farming. Since 2008 the majority of intensive shrimp farms have shifted from black tiger shrimp to white leg shrimp due to several advantages including short culture duration, high production, low risks of diseases and loss. Generally, intensive shrimp ponds are rather small in area (0.2-0.5 ha). Stocking densities are higher for white leg shrimp (*P. vannamei*) (70-150 PL/m^2) compared to black tiger shrimp (20-35 PL/m^2). Shrimp seed is normally checked for pathogens of common diseases such as white spot, Taura and EMS (Early Mortality Syndrome) before stocking. The cultured shrimp is fed with industrial feeds. Water exchange is limited, so a more intensified management system with aeration, environmental monitoring, probiotic use, etc. is applied. After 90-100 days of culture for the white leg shrimp and 100-150 days for the tiger shrimp, the shrimps are harvested with expected yields of 10-15 tonnes/ha/crop and 3-7 tonnes/ha/crop for white leg and black tiger shrimps, respectively.

Although the management of intensive shrimp systems has been improved, the problem of diseases is still present and the major issue for the industry. To mitigate against this some modifications have been applied more recently.

Pond lining

Shrimp ponds are completely lined with HDPE plate on both the bottom and on the dykes. This makes it easier for water management and intermediate host control. There are two main farming types. In single phase farming, the shrimp seed is stocked in the same pond until harvested after a culture duration of 3-4 months. In double phase farming, shrimp PLs are first stocked in nursing ponds at a density of 500-1,000 inds.m^{-2} for 20-30 days. Once the shrimp reach a size of 2-3g they are moved to grow out ponds at a lower density of 100-150 inds.m^{-2}. The shrimp are harvested after 2-3 months of farming at a size of 30–35 g. Triple phase farming may be applied by moving the shrimp twice after the nursing phase to extend the culture duration and increase the size at harvesting.

Biofloc technology

Biofloc provides two important roles in managing the organic waste and supplying good nutritious feed for the cultured animals. Biofloc technology is applied by adjusting C:N ratio and supplying probiotics to a highly aerated pond environment in order to convert organic waste into a protein source for cultured shrimp. Biofloc technology needs a higher investment however, it allows a higher stocking density for the white leg shrimp culture and is applied mainly in the central coastline provinces.

Indoor culture technology

Indoor shrimp culture technology is widely used in advanced countries. In Vietnam, the Hai Nguyen company (Bac Lieu province) was the first to apply this highly efficient model. The metal frame of the culture pond is covered in a HDPE plate. The system is well equipped with facilities for water quality management. Shrimp is stocked at a very high density of 200-300 inds/m^2. After 100-105 days of farming, the shrimp is harvested at a size of 30 inds/kg and the yield reaches about 80 tonnes/ha. Recently, several companies have adopted this model, e.g. Truc Anh Company, Viet-Uc Company, etc. The advantage of this system is that the water can be treated and reused, but the very high initial investment is a constraint.

v. Intensive fish farming systems

Farming high value fish in brackish water has been developed recently due to the ongoing issue of shrimp diseases and subsequent losses. The main cultured species is Asian seabass with seed produced artificially. The fish is stocked in the ponds previously used for shrimp farming and provided industrial feed. The management style is similar to intensive shrimp farming systems.

b2. Water-based systems

i. Marine fish farming systems

A diverse range of fish species are cultured in Vietnam's marine environment including divers with grouper, cobia, seabass, red drum (*Sciaenops ocellatus*), Pompano (*Trachinotus* sp.), snapper (*Lutjanus* spp.), red sea bream (*Pagrus major*), rabbit fish (*Siganus guttatus*), yellow tail (*Seriola dumerili*), and sand bass (*Psammoperca waigiensis*), etc. The most popular marine cultured fish species are grouper, cobia and sea bass. Marine fish farming is mainly performed in floating net cage systems. In the period from 2010 to 2015, the number of marine fish cages were increasing continuously from 30,031 units in 2010 to 172,119 units in 2015. Seed for most marine cultured species is artificially produced but some (grouper, snapper, red sea bream, rabbit fish, yellow tail, sand bass) still rely on wild fry. Both trash fish feed (Feed Conversion Ratio (FCR) 4.5-10) and industrial feed (FCR 1.8-2.4) are used in marine fish farming systems.

ii. Spiny lobster farming systems

Spiny lobster farming is flourishing in five south central coastline provinces. Khanh Hoa is the earliest province to develop a lobster farming industry, followed by Phu Yen and then Binh Dinh, Ninh Thuan and Binh Thuan provinces. Fixed, floating and submerged cages are used for lobster culture. The number of lobster cages in 2010 was 51,797 units, which increased to 56,942 units in 2015. Lobster production has also increased from 1,397 tonnes to 1,657 tonnes in respective years. The spiny lobster species farmed in these 5 provinces are the tropical rock lobster (*Panulirus ornatus* - 74.2%), the green lobster (*P. stimpsoni* - 22.7%), red lobster (*P. longipes* -1.2%) and bamboo lobster (*P. polyphagus* - *1*.9%). Currently lobster farming still relies on wild inputs of seed and feed.

iii. Seaweed cultivation

Seaweed culture in Vietnam is concentrated in the south-central coastline region with species of cottonii, *Kappaphycus alvarezii* and *Caulerpa lentillifera*. The area of seaweed cultivation tends to decrease year by year due to the unstable market and unfavourable weather, especially in the fog season.

Key aquaculture products

A. Striped catfish

Striped catfish, mainly raised in the MRD, are considered one of the success stories of aquaculture in Vietnam.

a. Production

Catfish are raised in 10 provinces within Vietnam: An Giang, Dong Thap, Tien Giang, Can Tho, Vinh Long, Ben Tre, Hau Giang, Soc Trang, Tra Vinh, Kien Giang of the MRD, and two provinces not in the MRD: Tay Ninh and Quang Nam (Table 8) with total area under farming of 3,439 hectares in 2016.

In the ten provinces in the MRD, Dong Thap and An Giang have the highest catfish farming areas. Kien Giang has ceased culturing catfish since 2015.

The farming area of striped catfish was at its highest at 6,020 ha and 5,911 ha in 2009 and 2011 respectively. The area has subsequently reduced to 5,500 ha from 2014 to 2016. However, the quantity of fish being produced did not reduce but remained at 1.1-1.2 MT of live fish (Figure 23).

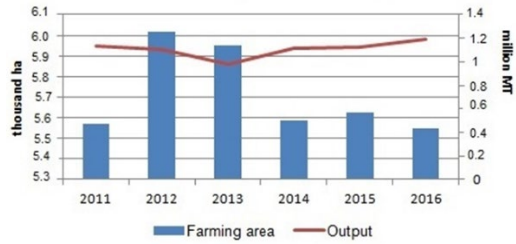


Figure 23 Striped catfish farming area and output in the Mekong River delta from 2011 to 2016 (Source: VASEP, 2017b)

i. Seed production

In the Mekong River delta, there are 230 hatcheries producing larvae and more than 4,000 nursery farms producing 22-25 billion larvae that require a pond area of 2,250 ha to produce 3-5 billion fingerlings. The striped catfish hatchery and nursery are operated at a household level. The survival rate at nurseries is low (4-10%) and thus the rearing from larvae to fingerling is quite specialised. While the seed selection program for striped catfish has been done in RIA 2

Table 8 Farming area of *Pangasius* catfish within the MRD provinces up to 31/12/2016 (Source: VINAPA)

Provinces	Farming area		Output		Yield (tonne/ha)
	In 2016 (ha)	**Compared to 2015**	**In 2016 (tonne)**	**Compared to 2015 (%)**	
An Giang	667	10	215,412	13	323
Ben Tre	734	-5	164,530	4	224
Can Tho	567	-4	163,666	9	289
Dong Thap	1,089	-3	412,193	7	378
Hau Giang	91	-10	26,385	-5	291
Kien Giang	0	-100	0	-100	-
Soc Trang	2	-96	600	-95	316
Tien Giang	98	5	37,516	10	384
Tra Vinh	24	250	8,230	592	339
Vinh Long	167	-34	48,938	-29	293
Total	**3,439**	**-4,5**	**1,077,470**	**5**	**313**

for several years the survival rate of fingerlings has not been improved.

ii. Marketable fish production

During the last decade there has been a marked change in the striped catfish farming systems in the MRD. Before 2001, three farming systems namely cage, pond and pen (fence) culture contributed almost equally to the total production of striped (tra) catfish (Figure 24). However, since 2003 pond culture has gradually developed, and currently this system dominates the striped catfish farming industry in the MRD. Pond farming has become the dominant operation because of the relatively faster growth rate of cultured fish, lower production cost, and better flesh quality and appearance meeting all the criteria for export.

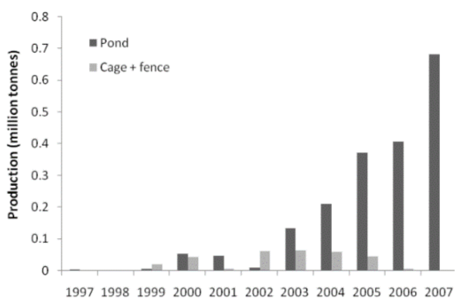


Figure 24 Change of striped catfish farming systems from cage to pond culture (Lam et al., 2009)

The catfish farming operation in Vietnam, however is rather different from other production systems in Asia as it operates on a large pond area (3,000-10,000 m^2), high water depth (3.5-4.5 m) and at a high rate of daily water exchange (20-30%).

The stocking density is highly varied (18-125 fish.m^{-2} or 5-31 fish.m^{-3}) depending on the size and availability of seeds and the financial capacity of the farmers to purchase seeds. Most farms (74%) stock the seed on multiple occasions (staggered stocking) within a short time frame.

The majority of farms use industrial feed which is purchased directly from the feed mills or from local feed stores. The fish is harvested at the size of 0.6 to 1.5 kg (mean 1 kg) after a culture duration of 6-7 months. Striped catfish is raised mainly for export i.e. 90-95%. The product is sold directly to processors after negotiating a price and testing the quality. The processors test fish samples on appearance, flesh colour and residues of banned antibiotics and chemicals prior to purchasing. It is rather unusual that no middlemen are involved in the marketing process. Grow-out farmers often make a prior contract with processors.

In order to maximize profits, several companies have applied a closed striped catfish production chain, ranging from breeding, nursing, farming, processing and export. Certification was introduced as a form of market governance to control over production and to secure their commercial and institutional interests. There have been six international standards applied to fish production (Table 9). In addition, Vietnam has issued a national standard namely VietGAP. In 2016 3,000 ha of catfish farming area (60% of the total) have obtained an international certification such as GAP while 967.24 ha had achieved the national standard, VietGAP.

b. Feed production

Formulated pellets are mainly used in striped catfish, red tilapia, climbing perch, snakehead fish, frog, and shrimp culture. However, trash fish remains as one of the major feed components for marine fish culture.

The annual production of formulated feed for aquafeed were 2.7 and 3.0 million tonnes in 2015 and 2016, respectively. For striped catfish farming, formulated feed is completely used and an estimation of 1.6-1.8 million tonnes was produced in 2015. There are around 50-60 mills specialised in producing feed for striped catfish. The top five aquafeed mills in Vietnam in 2015 were Viet Thang, Proconco, Co May, Vina and GreenFeed with an annual production of 100,0000-300,000 tonnes. Aside from specialised industrial feed mills, there are other feed mills owned by frozen factories. They produce feed for farming within their production chain. The five top mills producing feed for their own use are Vinh Hoan, Tay

Table 9 Name of the six main standards applicable to Vietnamese striped catfish production (Belton et al., 2011)

Scheme	Certifier	Notes
GlobalGAP	GlobalGAP	GlobalGAP is a body established by a partnership of major European retailers which certifies crops, livestock and aquaculture products
Best Aquaculture Practice (BAP)	Aquaculture Certification Council (ACC)	Established by the Global Aquaculture Alliance – an industry body for the promotion of aquaculture. ACC certified shrimp popular in the USA, ACC standards for tilapia and channel catfish also operational. Standards for striped catfish not yet made public
***Pangasius* Aquaculture Dialogue (PAD)**	Aquaculture Stewardship Council (ASC)	One of 10 dialogues for different groups of species initiated by the World Wildlife Fund (WWF). Standards to be certified by the newly established independent ASC
Butler's Choice	Butler's Choice	Dutch company established with the aim of guaranteeing high quality, ethically sourced foods. Shipped only 500 t of striped catfish in 2007
Safe Quality Food 1000 (SQF 1000)	Food Marketing Institute	Food safety focused standard favored by Vietnamese government and promoted by DoF but yet to achieve widespread uptake. SQF 2000 certification for processors has been attained by some companies
Naturland	Naturland	German organic certification body. Two Vietnamese farms currently certified

Nam, Nam Viet, Sao Mai, Hung Ca with an annual production of 100,000-200,000 tonnes.

c. Striped catfish processing and trade

EU (a reduction of 8,4%) (Table 10).

The main markets in 2016 were USA (22.6%), China and Hong Kong (17.8%) and the EU (15.2%) (Figure 25) and in

Table 10 Exportation values of Pangasius catfish in 2016 (Source: GSO, 2016)

Countries	Nov. 2016	From 1/1/2016 to 31/12/2016)		
	Value (USD million)	**Value (USD million)**	**Increased (%)**	**Compared to 2015 (%)**
USA	34.36	387.47	22.6	22.8
China and Hong Kong	35.11	304.784	17.8	88.7
EU	20.921	261.125	15.2	-8.4
ASEAN	11.293	135.221	7.9	-0.2
Mexico	6.724	84.367	4.9	-12
Brazil	4.983	68.014	4	-12.5
Colombia	3.818	55.357	3.2	-5.4
Arab Saudi	3.895	51.309	3	-16.6
Other	34.242	367.244	21.4	-1.8
Total	**155.345**	**1,714.89**	**100**	**9.6**

There are about 100 striped catfish frozen factories in Vietnam. Most are in the MRD. Most of these factories are equipped with advanced facilities and technologies which allow the automation of several stages of the production line to produce added value products.

The total value of striped catfish export in 2016 was 1,714 million USD (a 9.6% increase compared to 2015), in which 387 million USD from the USA market (22.8% increase), 304,7 million USD from China and Hong Kong (88.7% increase) and 261 million USD from the

first six months of 2017 China and Hong Kong had become the primary market, accounting for 30%.

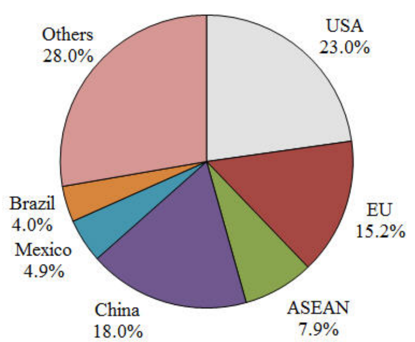


Figure 25 The value shared by importing markets of Viet Nam Pangasius in 2016 (Source: VASEP, 2017b)

Table 11 Shrimp hatcheries in 2016

Species	Hatchery number	Seed production (billion PLs)	Brood-stock (inds)
Black tiger shrimp	1861	30	30,000
White leg shrimp	561	100	200,000

The top 10 *Pangasius* export companies in 2016 were Vinh Hoan, Bien Đong, Nam Song Hau, Hung Vuong, Nam Viet, IDI, Agifish, Hung Ca, Go Dang and Truong Giang with 55% of the total export revenue (Figure 26).

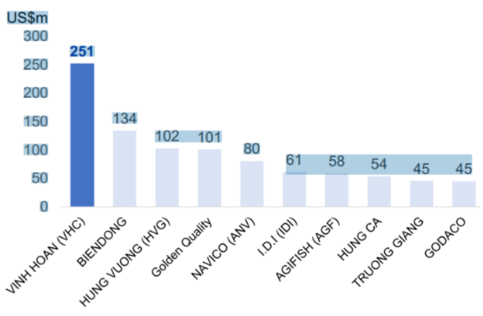


Figure 26 Top ten of Pangasius catfish export companies in 2016 (Source: VASEP, 2017a)

B. Shrimp

a. Shrimp production

Marine shrimp is the leading export item of the seafood industry of Vietnam with two main products – the black tiger shrimp (*Penaeus monodon*) and the white leg shrimp (*Litopenaeus vannamei*). Shrimp farming in brackish water occupied a particularly important position in the strategy of economic development of aquaculture industry in Vietnam over last 10 years.

i. Shrimp seed production

The provinces with a high capacity for shrimp seed production in the Mekong River delta are Ca Mau and Bac Lieu. The amount of shrimp seed (PL) produced locally cannot meet the need for the growing-out demand with only 25% of the demand met. Shrimp seed in the MRD has to be imported from the central provinces such as Ninh Thuan and Binh Thuan. Soc Trang alone has to import 100% of its shrimp seed (15,000 million PLs). Ca Mau is the only province with the black tiger shrimp broodstock, but again here almost all of shrimp seed must be imported from the central provinces. Due to the high demand all over the region it is very difficult to control the quality of seed and disease management (Table 11 and Table 12).

ii. Marketable shrimp production

Shrimp farming has seen a remarkable growth in terms of area, production and export value. The area of shrimp farming in 2016 reached 700,000 hectares, with the MRD accounting for 91% of total shrimp farming area, i.e. 1.15 times the area compared to 2010, and an average annual increase of 3.12% per year. In particular, black tiger shrimp farming area reached 570,000 ha (the MRD occupying 94%) and the white leg shrimp farming area reached 130,000 ha. Shrimp farming production in 2016 reached 650,000 tonnes (the MRD producing 80.61% of this) an increase of 1.5 times that of 2010 with an average increase of 10.59% per year. The production of black tiger shrimp reached 250,000 tonnes (the MRD accounted for 85.5%, a decrease of 16.79% compared to 2010); and the production of white leg shrimp reached 400,000 tonnes (the MRD accounting for 72.0%, an increase and 3.32 times that of 2010 and an average annual growth of 35%. The export value for shrimp in 2016 reached USD 3,150 million, accounting for 45% of total seafood revenue; of which black tiger shrimp contributed USD 1,150 million (36.5%) and white leg shrimp USD 2,000 million (63.5%).

Ca Mau province is the biggest producer in terms of shrimp culture area in the MRD as well as in the whole country (Figure 27).

Table 12 Postlarvae production and import (million PLs) in the Mekong River delta in 2014

Province	Black tiger shrimp			White leg shrimp		
	Hatchery	**Local production**	**Import**	**Local hatchery**	**Local production**	**Import**
Long An	1	118	82	-	-	3,200
Tien Giang	1	3	255	-	-	2,240
Ben Tre	19	72	2,178	11	480	5,587
Tra Vinh	75	900	1,040	1	6	2,674
Soc Trang	2	300	1,700	-	-	15,000
Bac Lieu	170	6,000	3,530	11	7,500	1,500
Ca Mau	874	9,073	8,670	-	58	6,141
Kien Giang	25	450	3,808	1	910	1,015
Total	**1,167**	**16,916**	**21,263**	**24**	**8,954**	**37,357**

Source: DARD and 8 coastal provinces in the MRD

Table 13 Area (ha) of black tiger shrimp farming in the Mekong River delta in 2014

	Province	Intensive	Improved extensive	Rice-shrimp	Mangrove-shrimp	Total	% in total
1	Long An	508	492	1,000		2,000	0.34
2	Tien Giang	582	1,517	555	2,654	5,308	0.90
3	Ben Tre	1,491	20,676	7,347	29,514	59,028	10.00
4	Tra Vinh	3,511	14,088	3,057	20,656	41,312	7.00
5	Soc Trang	12,155	44,900	57,055		114,110	19.33
6	Bac Lieu	9,800	74,921	30,500	6,990	122,211	20.70
7	Ca Mau	1,600	60,200	43,215	157,789	262,804	44.52
8	Kien Giang	100	17,048	77,273	94,421	188,842	31.99
Total		**29,747**	**188,942**	**206,847**	**164,779**	**590,315**	**100.00**
Percentage		5.04	32.01	35.04	27.91		

Source: DARD and 8 coastal provinces in the MRD

Table 14 Farming area (ha) of white leg shrimp in the Mekong River delta from 2008 to 2014

	Province	2008	2010	2011	2012	2013	2014	AG (%/year)	% in 2014
1	Long An	120	958	2,108	2,408	2,711	5,700	90.30	0.09
2	Tien Giang	184	669	792	830	1,348	1,380	39.91	0.23
3	Ben Tre	176	773	1,955	2,443	5,396	5,113	75.33	8.39
4	Tra Vinh	68	34	32	529	2,323	5,151	105.70	8.45
5	Soc Trang	145	295	1,470	4,411	15,542	27,017	138.99	44.33
6	Bac Lieu	3,504	3,429	3,643	3,248	4,897	8,076	14.93	13.25
7	Ca Mau	0	84	89	2,361	3,535	6,600	-	0.11
8	Kien Giang	280	746	1,150	1,063	1,158	1,915	37.77	3.14
	Total	**4,477**	**6,988**	**11,239**	**17,293**	**36,910**	**60,952**	**54.53**	

Source: DARD and 8 coastal provinces in the MRD

Black tiger shrimp farming in coastal provinces in the MRD include intensive systems (5.04%), improved extensive systems (32.01%), rotated black tiger shrimp - rice systems (35.04%) and integrated mangrove - shrimp farming (27.91%). Ca Mau province has the largest area of black tiger shrimp farming accounted for 44.52% of total area in the MRD (Table 13).

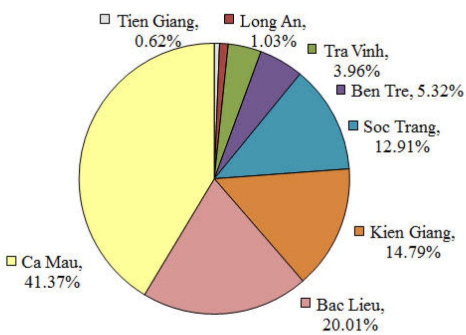


Figure 27 Marine shrimp culture area shared by eight coastal provinces in the Mekong River delta in 2016

White leg shrimp culture in the MRD began in 2008 based on the Decree No. 456/QD-BNN-NTTS issued on 4/2/2008 by the MARD. In 2014, the total white leg shrimp farming area in eight coastal provinces of the MRD was 60,952 ha, an increase of 13 times when compared to 2008 (4,477 ha) with an average growth rate of 54.53% per year (Table 14).

Different from the black tiger shrimp, the white leg shrimp culture was only allowed to develop within intensive systems in the coastal provinces of the MRD. In particular, Soc Trang province is the biggest white leg shrimp producer in terms of farming area with 27,017 ha (44.33%) and followed by Bac Lieu (13,25%), Ca Mau (10.83%), Long An (9.35%), Ben Tre (8.39%), Tra Vinh (8.45%) and Kien Giang (3.14%) (Table 14 and Figure 28).

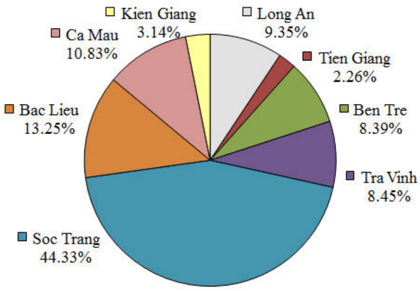


Figure 28 White leg shrimp culture area shared by eight coastal provinces in the Mekong River delta in 2014

In combination with the increased farming area, the production of marine shrimps in general and of white leg shrimp and black tiger shrimp in particular has increased year on year (Tables 15, 16 & 17).

Ca Mau province is the biggest black tiger shrimp producer in terms of production (40.27%) followed by Bac Lieu, Kien Giang, Ben Tre, Soc Trang, Tra Vinh, Tien Giang and Long An.

Soc Trang province is the biggest white leg shrimp producer in terms of production and followed by Ca Mau, Ben Tre, Bac Lieu, Tra Vinh, Kien Giang, Tien Giang and Long An.

Table 15 White leg shrimp production (tonne) in the Mekong River delta from 2008 to 2014

	Province	2008	2009	2010	2011	2012	2013	2014
1	Long An	*120*	*1,783*	*2,965*	*5,407*	*7,393*	*10,659*	*13,110*
2	Tien Giang	*1,987*	*2,116*	*7,842*	*8,577*	*7,452*	*13,937*	*16,960*
3	Ben Tre	*752*	*1,360*	*5,051*	*20,413*	*18,099*	*43,996*	*39,093*
4	Tra Vinh	*286*	*354*	*106*	*160*	*797*	*8,532*	*22,334*
5	Soc Trang	*574*	*1,080*	*1,168*	*5,821*	*17,468*	*50,682*	*67,159*
6	Bac Lieu	*16,315*	*17,041*	*15,966*	*16,962*	*15,123*	*22,801*	*31,000*
7	Ca Mau	*0*	*0*	*462*	*401*	*10,625*	*23,403*	*40,859*
8	Kien Giang	*3,000*	*8,126*	*10,800*	*13,020*	*12,921*	*13,728*	*19,476*
Total		**23,034**	**31,860**	**44,360**	**70,761**	**89,878**	**187,738**	**249,991**

Source: DARD and 8 coastal provinces in the MRD

Table 16 Marine shrimp farming production (tonne) in the Mekong River delta from 2005 to 2014

	Province	**2005**	**2010**	**2011**	**2012**	**2013**	**2014**	**AG (%/year)**
1	Long An	8,128	6,487	7,209	9,986	11,808	14,810	6.9
2	Tien Giang	7,949	15,269	16,884	11,961	18,544	21,620	11.8
3	Ben Tre	20,952	27,751	37,028	34,598	52,334	54,300	11.2
4	Tra Vinh	13,738	21,254	24,032	10,668	20,013	35,047	11.0
5	Soc Trang	42,837	61,128	33,641	40,435	72,762	82,199	7.5
6	Bac Lieu	61,983	64,627	69,045	73,877	85,626	96,743	5.1
7	Ca Mau	81,100	107,964	116,992	122,504	138,314	139,967	6.3
8	Kien Giang	23,794	35,737	39,601	42,216	41,978	51,430	8.9
Total		**260,481**	**340,217**	**344,432**	**346,245**	**441,379**	**496,116**	**7.4**

Source: DARD and 8 coastal provinces in the MRD

Table 17 White leg shrimp production (tonne) in the Mekong River delta from 2008 to 2014

	Province	2005	2010	2011	2012	2013	2014
1	Long An	8,128	3,522	1,802	2,593	1,149	1,700
2	Tien Giang	7,949	7,427	8,307	4,509	4,607	4,660
3	Ben Tre	20,952	22,700	16,615	16,499	8,338	15,207
4	Tra Vinh	13,738	21,148	23,872	9,871	11,481	12,713
5	Soc Trang	42,837	59,960	27,820	22,967	22,080	15,040
6	Bac Lieu	61,983	48,661	52,083	58,754	62,825	65,743
7	Ca Mau	81,100	107,502	116,591	111,879	114,911	99,108
8	Kien Giang	23,794	24,937	26,581	29,295	28,250	31,954
Total		**260.481**	**295,857**	**273,671**	**256,367**	**253,641**	**246,125**

Source: DARD and 8 coastal provinces in the MRD

b. Shrimp feed production

Intensive shrimp farming in Vietnam use 100% industrial feed produced by several companies such as CP (Thailand), Cargill (USA), Grobest (France), Uni-President (Taiwan), TomBoy, etc. Most feed mills are located in the southern provinces such as Long An, Tien Giang, Dong Thap and Can Tho. Feed distribution to shrimp farms is mainly through the network of feed stores in shrimp farming provinces. The total shrimp feed production in 2016 was 800,000 tonnes.

c. Drugs and chemicals

Most of drugs and chemicals for marine cultured shrimp are imported by local and foreign companies and distributed through the network of drug and chemical stores in the country. The domestic production of drugs and chemicals for shrimp farming has not been developed. The domestic enterprises only produce simple chemical substances such as limes. Quality management is thus dependent on drugs and chemicals from foreign companies.

d. Shrimp trading channel

The main channel to distribute cultured shrimp from farms to consumers and processing plants is through intermediate traders such as collectors, middlemen, wholesalers, retailers. There are few farmers who sell harvested shrimp directly to the seafood processing plants. 69% of all shrimp farms sell their products to middlemen and wholesalers, with 24% to collectors, and only 7% to export processing plant.

e. Shrimp processing and export

In 2015, there was around 200 enterprises involved in the processing and exporting of shrimp products with a total capacity of nearly 1 million tonnes per year. Most shrimp processing plants are concentrated in the MRD provinces, some in the central and south-central provinces. The number of shrimp processing factories within the provinces of the MRD (accounting for 60% of the total number in the country) include: 34 in Ca Mau, 22 in Kien Giang, 33 in Bac Lieu, 16 in Soc Trang. Some of the larger export companies have built their own shrimp seed hatcheries and grow-out farms to secure supply of raw materials to their processing factories such as Minh Phu, BIM, Toan Cau, etc. The total designed capacity of these enterprises is about 500000 tonnes of commercial products per year. Ca Mau province has the highest designed capacity reached to 190000 tonnes per year followed by Soc Trang (100000 tonnes), Bac Lieu (100000 tonnes) and Kien Giang (50000 tonnes).

f. Markets for shrimp product

i. Domestic market

Domestic consumption accounts for less than 10% of the total processed shrimp products. The distribution system is still dominated by local restaurants and/or supermarkets.

ii. International market

Vietnam is one of the leading shrimp suppliers in the region. To date, the shrimp export markets of the MRD businesses have spread over the territories of more than 50 countries in the world. Some of the main export markets for the Vietnamese shrimp are the United States, EU, Japan, China, Hong Kong, Canada, Korea, ASEAN, Australia, Brazil, Mexico, etc. However, the main markets of the MRD shrimp remain the United States, Japan and EU, of which the USA is the biggest import market. The ratio of these three main markets is about 70-80% of the total export turnover of shrimp products annually.

3.2.2 Thailand

The population in Thailand in 2019 was estimated as 69.63 million and the GDP was USD 386674 million, GDP per capita at USD 5814.77, and fisheries GDP at USD 2947 million (*Yenpoeng,* 2017). Thailand covers an area of 514,000 square kilometres located in the middle of mainland Southeast Asia with a coastline of 2,614km. Over one million hectares of coastal areas with a great potential for coastal aquaculture. Aquaculture production in Thailand was estimated to be 0.897 million tones and valued approximately USD 2.30 billion. Aquaculture activities in Thailand have been promoted to replace the decreasing capture fish production (Figure 29).

Production systems

Aquaculture operations are approved or prohibited based on environmental assessment under a new zoning exercise leading to the large-scale removal of fish pens and cages from lakes, rivers and reservoirs. Finfish farming dominates inland aquaculture; however, shrimps farmed in coastal aquaculture in Asia are still expanding and are a major source of foreign trade earnings for a number of developing countries in Asia. A series of new aquaculture technologies and high-yielding farming systems have been introduced with an environmentally friendly and sustainable purpose.

Aquaculture species

Thai aquaculture can be separated into two main categories: freshwater aquaculture and brackish water aquaculture. The five most important freshwater species, in terms of annual production, are Nile tilapia, catfish, silver barb, giant prawn, and snakeskin gourami. The most important brackish species cultivated are fish such as barramundi and grouper, shrimps, shellfish, and other crustaceans such as mud crab.

Key aquaculture products

Marine shrimp is the predominant species and makes a major contribution to export earnings. In 2015, marine shrimp production was 296100 MT followed by shellfish and fish. Farmed aquatic plants included are mostly microalgae which are used as live feed. The non-food products included are ornamental fish and pearl. There are about 350000 owners operating the ornamental fish trade in Thailand. The value of exported ornamental fish species was approximately USD 15.29 million.

History of Aquaculture

Nile tilapia (*Oreochromis niloticus*), a fish presented to HM King Bhumibhol in 1964 by Emperor Akihito of Japan, began to breed prolifically in a palace pond. The Department of Fisheries built a breeding pond in every fishery station around the country for the fish, which soon was firmly established in Thailand. In the meantime, a pioneering work in the cultivation of snake-skinned gourami (*Trichogaster pectoralis*) in paddy fields was highly successful; the salt-dried fish has remains popular until today. The culture of catfish (*Clarias batrachus*) stole the scene in the early 1970s, with widespread environmental repercussions on other farming activities for the first time. The fish-poultry, and fish-duck combination were widely practiced. Frequent outbreaks of fish disease dampened the hopes of fish farmers; some fish diseases made the catfish ugly in the eyes of the public. A serious fish epidemic that swept Southeast Asia in the late 1970s was blamed on the catfish. A catfish replacement was found: the striped snakehead (*Channa striata*), a hardy fish that can be kept alive for a long time. The Directive also provides for the establishment of pollution reduction programmes for the designated waters.

Current status

Thailand has been one of the top exporters of fish and fish products for decades, but its exports have declined as its important farmed shrimp industry has encountered repeated problems with disease during the past few years, which are only gradually being overcome (Figure 30). Thailand is also a major processing and canning centre for tuna catches landed by a range of foreign long-distance fleets, but over the course of 2015 to 2017 weak global demand for canned tuna has suppressed revenue growth.

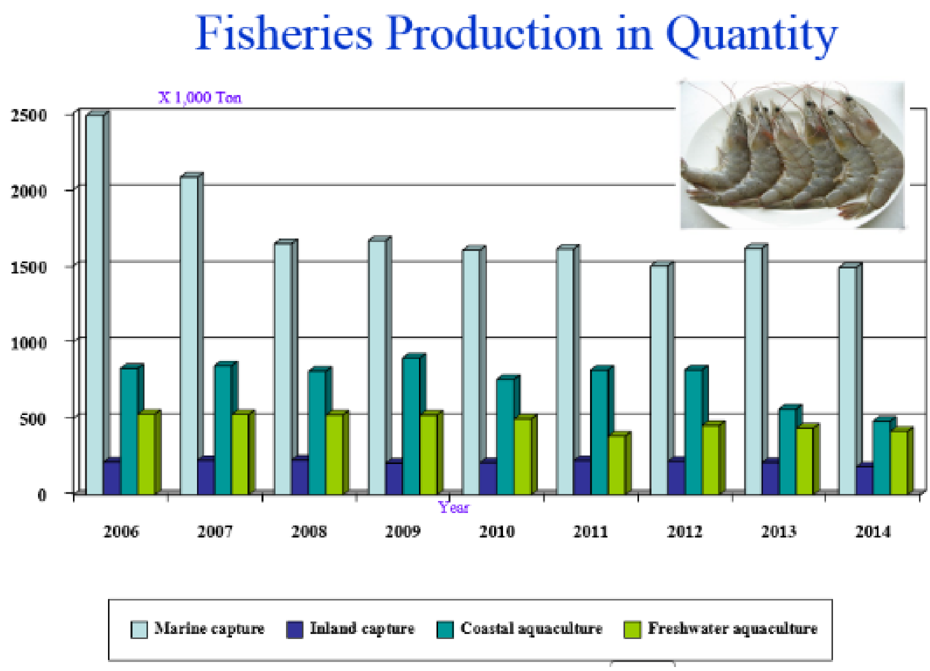


Figure 29 Thai fish production from capture fisheries and aquaculture year 2006 – 2014 (Department of Fisheries, 2016)

Figure 30 Fresh shrimp (22956262)

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4 EU Aquaculture

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In Europe, aquaculture accounts for about 20% of fish production and directly employs almost 70,000 people including part-time and full-time jobs in both marine and freshwater aquaculture.

The processing industry counts approximately 3700 companies. The mainstay of EU production is conserves and ready meals of fish, crustaceans, and molluscs.

Figure 31 Oyster farm (Mike Potenza)

The sector is largely composed of SMEs or micro-enterprises in coastal and rural areas. While EU aquaculture is renowned for its high quality, sustainability, and consumer protection standards the overall output has been more or less constant in volume since 2000. Over the same period global production has been growing by nearly 7% per year. This lack of growth has been partially explained by strict environmental regulations and a high bureaucracy burden that does not facilitate economic development.

Given the initial lack of production increases, the EC identified challenges facing aquaculture, including causes of stagnation and barriers to development, trying to give a new impetus to the sustainable development of aquaculture in the EU. Moreover, through the Common Fisheries Policy (CFP) reform, the EC intended to stimulate the aquaculture sector and in 2013 published the Strategic Guidelines presenting common priorities and general objectives at EU level. Four priority areas were identified in consultation with all relevant stakeholders:

(i) reducing administrative burdens,

(ii) improving access to space and water, (iii) increasing competitiveness, and (iv) exploiting competitive advantages due to high quality, health and environmental standards.

The European Commission (EC), together with the EU countries, have invested significant funds in the aquaculture sector to boost food security and economic development. Through its structural funds the European Union (EU) has invested €1.17 billion in the aquaculture sector over the period 2000–2014 and will have spent an additional, €1.72 billion over the period 2014–2020 through the European Maritime and Fisheries Fund (EMFF). The EMFF is the financial instrument to support the EU's maritime and fisheries policies for the period 2014–2020. It is one of the five European Structural and Investment Funds which complement each other and seek to promote a growth and job-based recovery in the EU.

Despite this investment, EU aquaculture production has not seen the expected increase in production. In fact, production volume in 2016 was 8% less than in 2000, while global production increased by more than 150%. These investments were aimed at making the EU aquaculture sector more successful and competitive by focusing on quality, health and safety, as well as, eco-friendly production to provide consumers with high-quality, highly nutritional and trustworthy products.

4.1 General techniques

There are many different techniques used in European Aquaculture which can be controlled or semi-controlled, in both natural and unnatural habitats, marine, brackish and freshwater environments, in various systems, both traditional and modern. However, there are 3 main types of European aquaculture systems; extensive, semi-intensive and intensive and are classified by the amount of human intervention involved.

Extensive freshwater aquaculture is a traditional practice that is carried out all over Europe. This farming method allows for higher production levels in comparison to natural ecosystems through the maintenance of both artificial and natural ponds. The species farmed in these ponds varies according to geographical location for example: different species of carp, catfish, crayfish and frog.

Semi-intensive freshwater fish farming sees a further increase in production levels from extensive aquaculture through providing supplementary feed, such as dry pellets, to allow for a higher stocking density and therefore greater production.

Intensive freshwater fish farming usually takes place in man-made environments such as raceways and tanks with modifications to allow for the control of environmental parameters. In these environments fish are grown until they are of marketable size. One technique used in this system is a flow-through system where the water from upstream is returned downstream after it has passed through the tanks. The other technique used is intensive recirculating aquaculture system (RAS) where the water stays in a closed circuit which allows for temperature, acidity, salinity, and disinfection to be controlled. It also allows for organic waste to be treated before disposure. This type of system is used throughout Europe and typically used for the farming of trout amongst other species but can also be used for marine species.

In marine aquaculture extensive fish farming takes place in natural habitats such as lagoons and coastal ponds. The processes are similar to the freshwater systems where here in lieu of ponds the lagoons are fertilized and cleaned every winter to enhance the development of aquatic fauna without the addition of supplementary food. While in the semi-intensive farming there is also the addition of feed using hatchery fry.

In intensive sea farming the fish are fed high-quality feed and given medication. They are kept in sea cages usually surrounded by nets which are anchored to the bottom and kept at the surface by a floating mechanism (Figure 32). These cages are usually kept near the shore and mainly house salmon, sea bass and sea bream.

Figure 32 Sea cage in Atlantic waters

The main species of shellfish farmed in Europe are oysters, mussels and clams. There are different techniques used for the farming of shellfish which vary according to environmental conditions and tradition methods. Shellfish farming includes bottom farming in shallow coastal areas, intertidal shellfish farming between high and low tide and floating systems such as rafts and longlines. Raft and longline methods allow for farming in deeper waters. In Galicia (Spain) mussels are cultivated on rafts whereas in Carlingford Lough (Ireland) they are dredged from the sea floor. Shellfish farming usually uses specimen from the wild with all nutrients supplied directly by the surrounding environment.

Seaweed farming usually takes place in coastal areas, which are sheltered from strong currents and winds. The seaweed is seeded onto ropes or nets which are then kept submerged. The kelp, *Laminaria digitata,* is the main seaweed cultivated.

Integrated Multi-Trophic Aquaculture (IMTA) is often applied to increase the productivity and reduce the environmental impacts of aquaculture through combining different tropic levels in the same system. This system is designed to recycle the by-products, including waste, from one trophic level species and introducing then as inputs in the form of fertilizer or food for another trophic level species reducing the overall waste output (Figure 33).

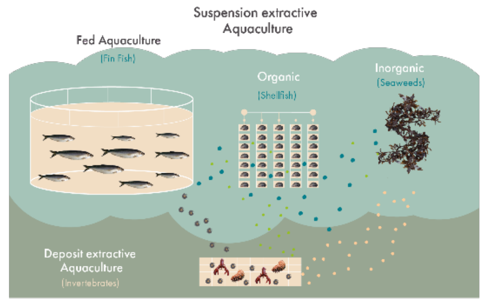

Figure 33 An IMTA system where finfish provide particulate organic matter (POM) for the extractive organic aquaculture (shellfish) which provide dissolved inorganic nutrients (DIN) for the inorganic aquaculture (seaweed).(©Malcolm Deegan 2021)

Aquaponics is another system where water is continuously recirculated through the system. This technique is an efficient way of producing food with its combination of fish farming and soilless plant farming. The by-products released into the water by the fish are passed into the hydroponic system where bacteria convert the waste into nitrates and nitrites which the plants absorb as nutrients while enhancing the water quality.

4.2 Production

Aquaculture production in Europe reached an estimated 10 year high of 1.4 million tonnes live weight (TLW) in 2017 representing one fifth of the EU's total fishery production. While marine aquaculture has accounted for more than 75% of the annual production from 2008 to 2017 (Figure 34). The contribution of the EU's aquaculture industry in global production was 4.3% in 2000 down to 1.6% in 2016.

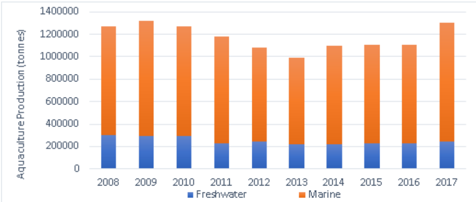

Figure 34 Annual aquaculture production by source (EU-28). Data adapted from Eurostat (online data code: fish_aq2a).

The top producing countries are Spain, the United Kingdom, France, Italy and Greece (Figure 35). In 2017, these countries accounted for approximately 73.7% of the total EU production, which has an approximate value of 5.1 billion EUR. Among the Member States, the United Kingdom had the highest share in terms of production value, with an estimated amount of 1.3 billion EUR, followed by France, Spain, Greece, and Italy.

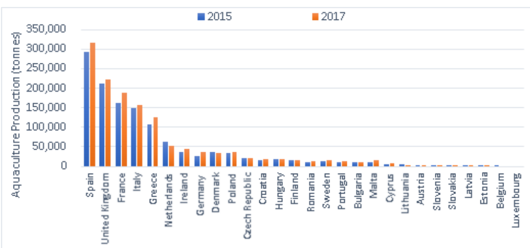

Figure 35 Aquaculture production by Member State (EU-28). Data adapted from Eurostat (online data code: fish_aq2a)

Species of interest

Aquaculture production within the EU is dominated by finfish and molluscs (Figure 36). The species that contribute most to the value of aquaculture output is the Atlantic salmon (*Salmo salar*), of which more than 90% were reared in the United Kingdom. Other important species of finfish are rainbow trout, seabass and seabream, which accounted for a collective proportion of about 30% of total EU production.

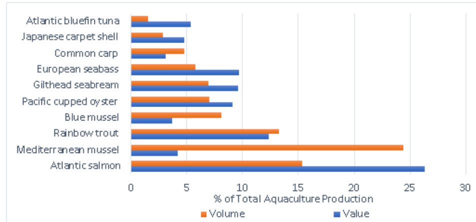

Figure 36 Main species in aquaculture production (EU-28, % of total production 2017). Data adapted from Eurostat (online data code: fish_aq2a).

The cultivation of Mediterranean mussel (*Mytilus galloprovincialis*) is the most important in terms of volume, with approximately 25% contribution of the total production quantity in 2017. The leading producers of shellfish within the EU are Spain, France and Italy. These Member States take up a major part in marine mollusc production in a global context.

4.3 Legislation on water quality

The Shellfish Waters Directive – 2006/113/EC, which came into force in December 2006, provides a compulsory criteria to be reached for water quality to allow for the protection and improvement of shellfish waters. It requires the Member States to designate waters that need protection to ensure sustainable and high-quality shellfish production though developing pollution reduction programmes.

To achieve its objective, the Directive sets out mandatory values for parameters applicable to designated shellfish waters, including the specific reference methods of analysis and minimum sampling and measuring frequency. The parameters assessed include pH, temperature, coloration, suspended solids, salinity, dissolved oxygen, and the presence of certain substances (hydrocarbons, metals, organohalogenated substances). The competent authorities for each EU country must take samples from the waters to verify their conformity. The following portions must conform to the established values: a) 100 % of the samples for the parameters 'organo-halogenated substances' and 'metals', b) 95% of the samples for the parameters 'salinity' and 'dissolved oxygen', and c) 75% of the samples for the other parameters.

The Water Framework Directive (WFD) provides a holistic legislative framework for the management, protection, and improvement of water resources. It establishes an integrated approach to water management that is based on natural geographical and hydrological formations, such as river basins, instead of administrative or political boundaries. It covers all waters across the EU, including inland surface waters, transitional waters, coastal waters, and groundwater.

The WFD sets out a classification scheme for water ecological status, which mainly comprises five categories: high, good, moderate, poor, and bad. Along with these categories, the directive also specifies a precise timetable for the implementation of management plans and monitoring systems, with 2015 as a target year for achieving good ecological status for all European waters or, at the latest, by 2027. Generally, the classification of the ecological status for each water category is based on the following quality elements as specified in Annex V of the WFD: a) Biological quality elements: phytoplankton, macrophytes, macroalgae, angiosperms, phytobenthos, benthic invertebrate fauna, fish fauna b) Hydromorphological quality elements: Hydrological regime, tidal regime, morphological conditions, river continuity and c) Physico-chemical quality elements: thermal, oxygenation, salinity, nutrient and acidification status, specific synthetic and non-synthetic pollutants, and priority substances.

Each country designed a programme for operational, surveillance and investigative monitoring to assess and record the status of these quality elements. A set of monitoring frequency is specified to achieve an acceptable level of confidence and precision, taking into account all parameters of each quality elements. Technical specifications and standardised methods for analysis and monitoring of water status are also provided to ensure the comparability of monitoring results. The Directive runs in 6-year cycles with the second cycle due to end in 2021.

Based on the first reporting period to 2016 the European Environment Agency reported around 40% of the surface waters (rivers, lakes and transitional and coastal waters) have been classified with good ecological status and potential. While only 38% of the surface waters recognized by the WFD are defined as having a good chemical status.

Hydromorphological pressures, diffuse sources, especially of agriculture, and atmospheric deposition, particularly of mercury, followed by point sources and water abstraction, were identified as the main pressures that significantly affected the status of water bodies.

The WFD is complemented by other EU policies, extending the scope of legislation on the protection and management of marine waters at a regional level, such as the Marine Strategy Framework Directive (MSFD, 2008/56/EC). The MSFD implements a comprehensive and integrated approach for the protection of marine environment and resources across Europe. It is the first regulatory framework of the European Union which relates to the sustainable use of marine waters and was adopted on 17 June 2008. The MFSD set a target for achieving the Good Environmental Status (GES) of marine waters by 2020. The Directive specifies that all Member States follow an ecosystem-based management strategy, taking into account the various elements of the marine environment. The MSFD sets out 11 qualitative descriptors of good environmental status, specifically related to biological diversity, non-indigenous species, commercial fish and shellfish, marine food webs, eutrophication, sea-floor integrity, hydrographical conditions, contaminants in the marine environment and in seafoods, marine litter and energy, including underwater noise.

The objectives and attributes of these descriptors have significant linkages. For instance, the main descriptor related to the effects of contaminants in the marine environment is closely linked with Descriptor 8, which deals with the accumulation of pollutants in commercial species such as fish and shellfish. It is also complemented by other legislation, such as the Environmental Quality Standard Directive (2008/105/EC), which mainly seeks to achieve good chemical status for surface waters. For this purpose, this directive develops environmental quality standards for the identified priority substances and pollutants posing a significant risk to the aquatic environment.

The linkages of the descriptors, as well as the complementarity of all relevant policy frameworks, are therefore an integral part of achieving the good environmental status of all European waters.

4.4 Challenges

Some of the challenges that European aquaculture face are worldwide challenges namely disease, genes, environmental impact, cost and conflict. The challenge unique to Europe is 'growth' particularly with the ambition to double EU production by 2030. To grow the industry needs to adapt and restructure to meet changing market demands, match evolving consumer preferences, multiple retail store domination of the market, competition from imported products, and competition with other foods such as chicken and pork. Strategic challenges include the need to avoid boom-bust scenarios, adapting policies to incorporate aquaculture, better communication to address public perceptions, and the inadequate financial capability of small companies to expand.

Disease, both known and new diseases, are one of the main challenges facing European aquaculture. The outbreak of diseases can lead to the mortality or disturbance of the aquatic organisms leaving them unmarketable and therefore cause an economic loss to the aquaculture industry. The transfer of infection is heightened in aquaculture as large numbers of aquatic fauna in a restricted area allowing for the transfer of the infection. In Europe farmed salmon are susceptible to a parasite known as sea lice and can cause problems in aquaculture as the quality and health of the fish can be damaged (Figure 37).

Figure 37 Parasitic sea lice recorded from salmon– Sourced: Marine Institute 2019

The effects of aquaculture on the environment is another challenge faced by European aquaculture. For example, the diseases present in farmed salmon may be transmitted to wild salmon if they escape causing further economic loss. Fish farms also generate effluent and release both antibiotics and chemicals into soil potentially polluting the water affecting their natural chemistry.

The potential to compromise the native gene pool is another challenge faced by European aquaculture if farmed fish escape and breed with native species. As with all aquaculture systems, the cost involved in setting up and operating an aquaculture industry can have many drawbacks especially in marine environments where operational factors such as reducing biofouling, removal of dead fish etc are all additional costly challenges before the potential impact of natural factors such as storms.

Local conflict from communities and other water users such as fishermen is another challenge that is often faced by European aquaculture with petitions and objections to planning being placed against the industry citing the affect the cages etc will have on the aesthetics of the area.

Climate change is also seen as a potential issue, along with feed quality, spatial requirements, and the need to selectively breed to improve the performance of all species.

4.5 Importing into the EU

Both exporting for the EU and importing into the EU requires careful review for each product the information pertaining to tariffs and taxes, custom procedures, rules of origin, trade barriers, and product requirements. Such is the level of detail required that the EU has established a specific portal with step-by-step guides for EU aquaculture exporters and importers to find detailed information to allow the best source or export market for each product they wish to export/import (Acess2Markets, Figure 38).

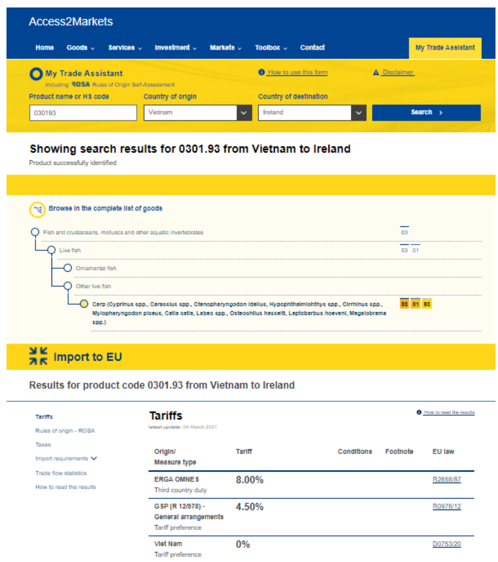

Figure 38 Website Acess2Markets overview of potential information contained for exporters and importers to the EU

On behalf of all EU Member States, the European Commission is the sole negotiating partner for all non-EU countries in questions related to import conditions for seafood and fishery products. Non-EU countries which are interested in exporting seafood and fishery products to the EU must be aware of the fundamental principles and philosophy of European Food Law, which forms the basis for our import conditions. Imports of fishery products into the EU are subject to official certification, which is based on the recognition of the competent authority of the non-EU country by the European Commission.

In addition to each exporting country having a competent authority responsible for performing official controls throughout the production chain, all fishery products, and countries of origin must be on a positive list of eligible countries for the relevant product. The eligibility criteria are: (1) Live fish, their eggs and gametes intended for breeding and live bivalve molluscs must fulfil the relevant EU animal health standards.
(2) The competent authority must guarantee that the relevant hygiene and public health requirements are met. EU hygiene legislation contains specific requirements regarding the structure of vessels, landing sites, processing establishments and on operational processes, freezing and storage. (3) Specific conditions apply for imports of live or processed bivalve molluscs (e.g. mussels and clams), echinoderms (e.g. sea urchins) or marine gastropods (e.g. sea-snails and conchs). Such products may only be imported into the EU if they come from production areas which have been approved by the competent authority and listed by the Commission on its website. (4) A residue monitoring plan which includes testing for residues of veterinary drugs, pesticides, heavy metals, and contaminants, must be in place to verify compliance with EU requirements. The plan (and results from the previous year's monitoring) must be submitted to the European Commission annually for approval. Countries with approved plans are listed. (5) Imports are only authorised from approved vessels and establishments (e.g. processing plants, freezer or factory vessels, cold stores), which have been inspected by the competent authority of the exporting country and found to meet EU requirements. (6) Audits by the Commission's Health and Food Audit and Analysis Directorate are carried out to verify compliance with the above requirements. Audits establish confidence between the Commission and the competent authority of the exporting country.

4.5.1 Import controls

Principles for veterinary checks are laid down in Council Directive 97/78/EC, Council Directive 2002/99/EC, Regulations 882/2004 and 854/2004. Inspections of consignments originating from third countries must be carried out on all consignments, at the first point of entry into the EU territory and at approved border inspection posts. Import controls are done in three consecutive steps (Figure 39).

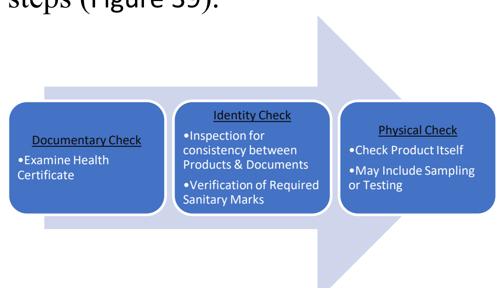

Figure 39 Import Controls (adapted from Vrignaud 2017)

Non-compliance with EU legislation will result in the shipment being refused. The exporter can then either a) Destroy the products; b) Re-dispatch these products to a non-EU country; or c) Return the products to the originating country.

4.6 Agricultural licenses

A notable feature of EU policy is that while it sets overall production targets for aquaculture, it does not indicate any specific targets for different types of product or specific species. The latest iteration of EU policy on Aquaculture, set out in the Strategic Guidelines for the sustainable development of Aquaculture states that aquaculture can contribute to the "overall objective of filling the gap between EU consumption and production of seafood in a way that is environmentally, socially and economically sustainable."

The Strategy also invited Member States to set out a national strategy to address the stagnation of EU aquaculture and reduce the licensing timescales. The strategy mandated that national strategy was to focus on the following themes:

(a) Reduce the licensing timescale through simplifying administrative procedures.

(b) Marine Spatial Planning (identify suitable sites, reserve for aquaculture).

(c) Enhance competitiveness (use European Maritime and Fisheries Fund (EMFF) to promote innovation, research, and growth).

(d) Exploit competitive advantages within the EU (quality, traceability, organics, labelling)

4.7 Future trends

The total volume of fish and shellfish produced in aquaculture is predicted to rise by 56 % to 772,000 MT, from 2010 to 2030, and the value to increase by EUR 2.7 billion (USD 3.4 billion). Subsequently 395,000 MT of additional feed will be required.

For cold water marine species, production is predicted to more than double by 2030 to provide an additional 192,000 MT of fish worth EUR 587 million (USD 734.3 million). This equates to an average 4 percent growth per year over the period. Salmon is predicted to remain the dominant species in this sector.

A similar 4 % per year growth trend is anticipated for warm water marine species, with an increase of 239,764 MT valued at EUR 1.2 million (USD 1.5 million). Sea bass and sea bream will continue to be the main species, with turbot and meagre growing in importance.

Production of freshwater species, which are particularly favoured in Eastern Europe, is expected to grow by 144,000 MT to 476,000 MT, with a value increase of EUR 487 million (USD 609.2 million). While rainbow trout and carp will continue to dominate production, an increasing volume of African catfish and sturgeon is predicted, with tilapia and barramundi producers contributing minor amounts.

Shellfish producers are predicted to increase their output by 30 %, growing an additional 197,000 MT by 2030, valued at EUR 427 million (USD 534.1 million). The annual growth rate is just 1.3 % and relies on overcoming issues with ongoing mortalities, especially in oysters.

The production of fishmeal and fish oil currently exceeds the amount used by the aquafeed industry and is estimated to be 3.3 % and 8.1 % respectively of global use for aquaculture. Additional feed requirements by 2030 would only exceed fishmeal and fish oil supply if it was all sourced locally. However, there is increasing potential for partial replacement of marine proteins and oils, which will reduce the impact on EU fish stocks. If aquaculture does not grow, then fishmeal and fish oil would be diverted to produce fish and shrimp in other countries, which would be returned to consumers in these forms.

Production of seaweeds, crustaceans such as freshwater crayfish and a few prawn species, and molluscs including octopus and sea urchins is relatively new in the EU, but it is expected to grow in importance. An increase in the use of integrated multi-trophic aquaculture systems, where species such as salmon, seaweed and mussels are combined in a production area will be applied to make best use of space and to mitigate environmental impacts.

Figure 40 Pacific oyster (c) Hans Braxmeier

4.8 Research ties with Asia

Aquaculture in Europe has created a knowledge-based sector with established international activities running in parallel with global aquaculture development. Several common research themes across the globe include the identification and implementation of common standards for aquaculture site planning, animal health, food product safety and farm governance, supporting sustainable aquaculture development. Research in Europe is strongly supported, for example during the 2014-2020 period, approximately 20% of the €6.4 million budget from the European Maritime and Fisheries Fund (EMFF) was invested in the aquaculture sector with sustainable aquaculture development as one of the main priorities. In addition, several research projects saw Asian partners actively involved in the research.

The German Federal Ministry for Economic Cooperation and Development (BMZ) and the Association of Southeast Asian Nations (ASEAN) funded a project on Standards in the South East Asian Food Trade (SAFT). This project was created to provide support to Cambodia, Indonesia, Laos, Myanmar and the Philippines. The SAFT project is a regional project supporting ASEAN with the implementation of food standards across the region.

The EU International Cooperation and Development (DEVCO) projects in Myanmar, and Cambodia aims to help reduce and ultimately eradicate poverty in developing countries through the promotion of sustainable development. Through the Myanmar Sustainable Aquaculture Programme (MYSAP), the EU is helping the government of Myanmar to tackle unsustainable management of fish stocks in coastal and inland freshwater areas where the fish population has significantly decreased, to the point where it threatens nutrition and income of rural populations.

Figure 41 A farmer tending his small-scale aquaculture pond, Ayeyarwady Delta, Myanmar (c) The WorldFish Center: Toby Johnson

MYSAP supports over 250 000 smallholder farmers and local small and medium-sized enterprises to increase their production and productivity by employing more environmentally sustainable and climate-resilient farming techniques in coastal and freshwater aquaculture value chains.

Figure 42 A fisherman in Myanmar casts his net © Maro Verli, European Union Delegation to Myanmar

The ASEM Aquaculture Platform was developed to establish an open and permanent space for dialogue between EU and ASEM parties that are involved in the development of sustainable aquaculture.

The Eurastip project, funded through the Horizon 2020 Societal Challenges 2 Food, programme has increased EU- Asia collaboration through exchange programs in education, research, and industry. National multi-Stakeholder platforms were created in Thailand, Vietnam & Bangladesh to help innovate education, training, and capacity building and to align standards and certifications.

TUNASIA (Tuning environmental competencies in Asian fishery education for sustainable development) is an ERASMUS+ funded project that focuses on the modernization and development of curricula for the qualification of students in a transdisciplinary education system in a network with companies, research institutions and stakeholders of the region.

Figure 43 Giant freshwater shrimp culture (Thailand)

The project strengthens European cooperation in transdisciplinary education and internationalization, which has been rather limited due to the strong scientific traditions in HE-education systems. This makes it possible to transfer knowledge about the transdisciplinary model to higher education and therefor enables the future generation of scientists and employees in enterprises to draw on synergies from different scientific directions.

Figure 44 Red Tilapia culture (Thailand)

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5 Seed production

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Methods described in this chapter are general practices used in medium and small holder freshwater fish farm in Thailand.

5.1 Broodstock management

Broodstock management is key to producing healthy seeds in large quantities. Therefore, it is necessary to become familiar with the different management methods particularly for commercial species. There are several species in southeast Asia, cultured in both freshwater and marine environments, that are considered to be economically important species including white pacific shrimp (*Litopenaeus vannamei*), Nile tilapia (*Oreochromis niloticus*), and Vietnamese pangasius, or basa fish (*Pangasius bocourti*). For more information on commercial species see Chapter 3 Aquaculture production in Asian countries. A healthy pond culture is a key consideration required for good management of a species.

5.1.1 Pond culture

The **pond dimensions** (size and depth) must ensure that the area is sufficient for fish to be able to live without stress which will result healthy reproductive cells in the parents. This can be done one of two ways a) using a large pond or b) having a low stocking density. The depth of the water within a pond has been shown to affect spawning in channel catfish.

The **photoperiod** or light period can directly affect ovarian development and stimulation of eggs, for example, goldfish raised at a temperature of 20 ˚C and exposed to light for 16 hours with 8 hours in the dark (16:8) found that the level of gonadotropins in the blood serum increased after the light receiving period resulting in the fish spawning once light is reintroduced. Similarly, it is recognized that light intensity may influence spawning of snakehead fish who spawn both in the morning and afternoon under low light intensities. Both temperature and light have been reported to have an effect on the level of hormones in the blood and the development of germ cells in the cyprinids.

Temperature has been shown to stimulate the reproductive systems in fish, for example higher temperatures is known to affect the ovulation of teleost fish however, it is not possible to conclude whether the stimulation occurs by increasing the temperature alone due to the many other environmental effects relating to egg development. Goldfish (*Carasius auratus*) raised in temperatures below 14 ˚C will not spawn however, when the temperature is increased to 20 ˚C, the fish will spawn every time.

Dissolved oxygen in the water must be at a constant high level, not be lower than 5 mg / L during the day, therefore the water used for culturing broodstock must be of better quality than the water used for raising fish. The levels of dissolved oxygen should not vary too much as this can cause stress. In additon, low oxygen levels in the water will disrupt the normal development of eggs and semen.

Changing the water will increase the oxygen, help to eliminate waste from excretion and food and help to stimulate the growth of eggs and semen. In the People's Republic of China, the fish farmers will normally drain the water 1-2 times per month depending on the water quality however, they will increase the frequency of water changes during the breeding season. Allowing the water to flow into the pond 3-5 times per month will have a positive effect on the fertility of eggs in comparison to broodstock raised in stagnant ponds.

The **salinity** of the water can influence spawning in some fish, especially in brackish water fish or those that can live in both freshwater and seawater, such as mullet and sea bass, etc. Female mullet, raised in freshwater, develop normal ovaries but do not spawn, while male mullets can produce semen and release it normally in freshwater.

The **stocking density** of broodstock within a pond can affect the development of germ cells. Stress is a known consequence of high stocking densities and can result in inhibiting the development of germ cells. In addition, there are higher levels of excretion within the pond, which is not conducive to the health of the reproductive broodstock within the pond.

In nature, fish will spawn in **tranquil areas** that are not disturbed by other animals and are ideally away from predators who predate of fish eggs. Therefore, the area for the nursery should be arranged away from noisy crowded areas as this will affect reproduction and spawning because fish will always panic.

Food and its composition are carefully chosen to stimulate the growth and development of fish germ cells. The nutritional compostion of the food and the quantity of feed provided to the brrodstock is carefully monitored to ensure there is no effect on the fecundity and subsequent size of their eggs. Broodstock with a lot of fat in the abdomen will spawn unhealthy eggs that are not suitable for breeding. For more on feed and feeding see chapter 6.

The '**social**' nature of pond aquaculture can be seen to be an influencing factor for spawning in ponds. For example, spawning can be simulated in mud carp through close proximity where within a pond only a portion of the fish have received injected hormones. The introduction of the opposite sex is another important social factor that can stimulating spawning as a result or either courtship behaviour before breeding and or the production of chemicals known as male "pheromones" which are released in the water which stimulate females to spawn.

5.2 Reproduction

5.2.1 Spawning season

Temporal changes can affect the growth of germ cells, with each species having different breeding seasons there are different environmental triggers playing a role in stimulating the reproductive system to ensure the ovaries of the fish will be ripe during the breeding season. Speices have adapted to different spawning seasons in order to avoid predators and to ensure there is sufficient food for the fry to eat once they have spawned, so even within the same are fish species may have different breeding and spawning periods. Where there is a water shortage in an area this may be reflected in a shorter breeding season in some species. In general tropical fish whose water sources are abundant throughout the year have a long spawning season and most will spawn multiple times during the spawning season

5.2.2 Sexual maturity and heritage

The broodstock must be sexually mature to ensure the production of healthy seeds. Sexual maturity can be determined based on the size and weight of the species in question (Table 18). Broodstock heritage and knowledge of the origin of the parents is essential to the production of aquatic seed.

5.3 Sources of aquatic seed

5.3.1 Spawning grounds

A broodstock can be sourced from their natural spawning habitat during their spawning season for example the Mekong giant catfish in the Chiang Khong district will migrate to their spawning area from April to June. However, it is largely only used as a source of fish for those species that cannot be reared as natural brooders in ponds, for example catfish need to be injected with hormonal stimulation before they can be inseminated. Broodstock obtained from these spawning habitats will have migrated there during their specific breeding period in order to spawn, therefore both the eggs and semen will be ripe in comparison to fish breeders obtained outside of their breeding habitats.

Table 18 Spawning season, maturation size and number of eggs for Commercial freshwater fish in Thailand

Species	Spawning season	Age year	Weight kg	Eggs per 1,000
Nile tilapia (*Oreochromis niloticus*)	Year-round	0.5-2	0.3-0.8	0.5 - 2
Common carp (*Cyprinus carpio*)	Year-round	1-3	1-4	100 -300
Grass carp (*Ctenopharyngodon idella*)	May-Nov	3-5	4-5	200 -400
Bighead carp (*Hypophthalmichthys nobilis*)	Apr-Sep	3-4	3-5	100-400
Silver carp (*Hypophthalmichthys molitrix*)	Apr-Sep	2-4	3-5	100-400
Silver barb (*Barbonymus gonionotus*)	Feb- Oct	1-2	0.4-1	50 - 200
Rohu (*Labeo rohita*)	May-Sep	1-3	2-4	100-300
Broadhead catfish (*Clarias macrocephalus*)	May-Oct	1-2	0.3-0.5	5-10
Walking catfish (*Clarias batrachus*)	Ma.-Oct	1-2	0.3-0.5	5-10
African catfish (*Clarias gariepinus*)	May-Oct	1.5-3	2-4	200-400
Striped catfish (*Pangasianodon hypopthalmus*)	Mar-Oct	2-3	4-8	300-1,000
Sand Goby (*Oxyeleotris marmorata*)	May-Oct	1-2	0.5-1.5	5-40

5.3.2 Natural habitat

Fish species caught outside of their spawning habitat and within the natural water system can result in the fish being at different stages of reproduction with only some fish ready to spawn. If the female fish have been fertilized, they can be bred immediately but if they are not ready, they may have to be adopted over a period. Fish caught from natural water resources are often traumatized due to the process of being caught and/or from the transportation. Where fish have to be adopted, it can be difficult to acclimatize them to their new surroundings of the hatchery and they are often a source of new parasitic diseases to the hatchery population. It is more economical to use fish from their natural habitat rather than raising them to become broodstock. It also reduces the potential of inbreeding, creating a more diverse population.

5.3.3 Grow-out Ponds

The production of good quality fish larvae is a skill which is vital to fish farmers and has become a trade as farmers cannot rely on natural breeders due to the time uncertainty and the quantity of stock. Fish captured for breeding can be injured because of the tools employed and may be so injured that they cannot be used for breeding. This regularly is the case in the current culture of catfish. Most aquaculture farms still use breeders caught from fishponds for human consumption, however the varying levels of reproduction is a problem in production planning. The best method is to raise the broodstock in grow-out ponds as a potential source of aquatic seed.

5.4 Culturing broodstock

Culturing broodstock is similar to that of an intensive culture system except that better conditions are required and therefore there are various factors that must be taken into consideration, such as the following:

The breeding pond is dependent on the size of the fish. If the fish are large, it is necessary to breed them in a bigger pond than for smaller fish. In both cases the depth of the pond should be approximately 1 - 1.5 meters. The water flow rate is important and providing a drainpipe or similar at the entrance that can transfer water easily is important as this will stimulate the growth of eggs and sperm, especially for fish that lay eggs in running water.

The stocking rate should be lower than in an intensive culture system. This will ensure better the water quality needed to stimulate the eggs and semen to full development. The optimal density rates for healthy broodstock: white carp (300-400 g) 800 fish in 1,600 m^{-2}; pangasius (2-3 kg) 200 fish in 1,600 m^{-2}; Chinese carp (420-630 kg) 200-250 fish in 1,600 m^{-2}; and walking catfish 400-600 fish in 1,600 m^{-2}.

The water quality used for the culture of broodstock must be of better quality than the water used for the intensive fishpond, with the level of dissolved oxygen present remaining high at all times. A decrease in the amount of dissolved oxygen at critical times during development has the potential to disrupt development of the eggs and semen. Changing the water will increase the dissolved oxygen levels in the water and will also help to eliminate the waste products from excretion and residual waste. The water needs be drained 1-2 times per month depending on the water quality and about 1-2 months before the breeding season, the water changes should increase to 3 times per month, allowing the water to flow into the pond and to overflow for 3-5 hours per time. This will increase the fecundity and fertility when compared to broodstock raised in stationary ponds.

Water temperature is another factor that influences the development of eggs and semen, but this is not a problem in Thailand where the water temperature is consistent throughout the year. Broodstock from native species require these high temperature therefore having the broodstock pond outdoors which ensure these temperatures remain high.

Food is an important factor in the development of eggs and semen, both in terms of quantity and nutritional value. The fecundity is affected in fish that are fed too little, or too much for example in rainbow and lake trout lake trout and in the native fish of Thailand this will affect the fertility of eggs and sperm. In general, raising broodstock in Thailand the daily feeding rate is approximately 1–2 percent of their body weight.

Breeding management, or lack of foresight in management practices have led to the indirect reduction in the size of fish species. The most likely cause is what is termed “Negative selection and Indirect selection" . Negative selection results from catching the larger fish to sell and raising the smaller fish as breeders. By not selecting the ‘fittest’ for breeding this can lead to a reduction in genetic diversity and diminishing of those genes resulting in high growth are constantly discarded though the sale of the largest fish for profit.

To ensure good management practices and a healthy broodstock into the future a number of key actions need to be taken: 1) Larger fish should be selected as the broodstock, 2) Broodstock of different ages are cultured in separate ponds, 3) Several fish should be used for breeding with each female fertilised by several males, and 4) Where the fry are observed to have slow growth rates it is necessary to introduce breeders from other sources to increase the ‘fitness’ of the broodstock with a diverse gene pool.

5.5 Fish eggs

There are 3 types of fish eggs, pelagic, semi buoyant and demersal eggs, which are found in aquaculture farming (Table 18).

5.5.1 Pelagic eggs

Floating, pelagic or buoyant eggs have a lower specific gravity than water as a result of several oil droplets located opposite the animal pole. There is no sticky mucus in the eggshell and the perivitelline space is narrow. Fish with eggs of this type include mackerel, tiger fish, eel, snakehead fish, snakeskin gourami, climbing perch, fancy carp, fighting fish, white snapper, mullet fish, etc.

5.5.2 Semi buoyant eggs

This type of egg has a specific gravity just below that of water. After the fish spawn, the eggs absorb water into the perivitelline space. This type of egg will float as long as there is water flow however it will sink in still water. The eggshell is similar to pelagic eggs in that it does not have a sticky substance to prevent it sticking to underwater materials. The eggs are transparent, with thin shells and have a wide perivitelline space. The incubation period is shorter than in other types of eggs. Fish that produce these types of eggs include silver carp, red-tailed black shark fish, black shark fish, and silver barb.

5.5.3 Demersal eggs

These eggs tend to have a higher specific gravity than water. They have a thick, opaque shell without oil droplets. The perivitelline space is narrow and absorbs less water. The hatching time is slower than in other types of fish eggs. This type of egg is also divided into 2 types, i.e. those eggs that are not attached to material (non-adhesive-demersal egg), such as tilapia and dragon fish, etc. and those eggs that attach to material (adhesive-demersal egg). This type of egg will form a sticky substance in the eggshell, when the fish lays their eggs and therefore when they come into contact with water these eggs can attach to various materials under the water. Adhesive demersal eggs are associated with giant catfish, striped catfish, sand goby, goldfish, and common carp, etc.

5.6 Breeding techniques

Breeding employs a variety of methods, depending on the type of fish, technology, conditions of the area and facilities available. Although there are currently various technologies, the breeding methods below are still widely used in various regions around the world. The breeding methods can be divided into 4 types:

5.6.1 Natural method

For natural propagation, males and females are placed together in a breeding area such as a small pond or an enclosure where they spawn naturally. This method is usually used, for example, to produce tilapias cheaply.

Table 19 Egg types of popular fish cultured in Thailand

Species	Type of egg	Type of breeding
Nile tilapia (*Oreochromis niloticus*)	Non-adhesive demersal	Natural Method
Common carp (*Cyprinus carpio*)	Non-adhesive demersal	Induced Natural Method
Silver carp (*Hypophthalmichthys molitrix*)	Semi buoyant	Induced Natural Method
Silver barb (*Barbonymus gonionotus*)	Semi buoyant	Induced Natural Method
Rohu (*Labeo rohita*)	Semi buoyant	Induced Natural Method
African catfish (*Clarias gariepinus*)	Adhesive-demersal	Artificial Method
Striped catfish (*Pangasianodon hypopthalmus*)	Adhesive-demersal	Artificial Method
Climbing pearch (*Anabas testudineus*)	buoyant	Induced Natural Method
Kissing gourami (*Helostoma temminckii*)	buoyant	Induced Natural Method
Snakehead fish (*Channa striata*)	buoyant	Induced Natural Method
Snake skin gourami (*Trichopodus pectoralis*)	buoyant	Induced Natural Method

5.6.2 Controlled natural method

This breeding method involves ensuring the spawning conditions reflect those of the species natural conditions. In some cases the pond needs the water to be changed regularly to reflect the natural conditions of a flowing environment. The fish spawn eggs can either be allowed to hatch in the pond or the eggs can be removed and hatched elsewhere. In Thailand this method is used for local species such as walking catfish and sand goby.

5.6.3 Artificial fertilization

The broodstock for artificial fertilization can be collected from natural water sources. These include ripe male and females that in some cases will need to be injected with hormones to stimulate ovulation. The artificial insemination itself involves the mixing of these eggs and semen when released into a container. Artificial insemination can be divided into 3 types, as follows:

The **wet method** was the first method used for the artificial propagation of fish by mixing eggs and semen in a container containing water. This method works for fish that have eggs that are buoyant and semi-buoyant but does not work for adhesive- demersal eggs. In addition, when removing eggs from a female the semen should be taken out afterwards (30 seconds maximum) and put into the mixture, because when the egg is out of water, the micro-pile where the semen enters will close quickly. If the semen is added after 30 seconds, then the fertilization rate will be reduced to 50 percent.

The **dry method** results in higher fertilization rates than the wet method. The eggs and semen are mixed in a dry container where the semen will coat the egg surface. When the eggs are incubated in the spawning tank, the water from the surge encourages semen to mix easily with the eggs. As a result, the fertilization rate is high. This method is suitable for fish that have adhesive- demersal eggs, such as pangasius. The dry method has the disadvantage that the blood, or waste, that is attached to the egg or semen cannot be washed off.

The **modified dry method** adds enough water to flood the eggs after mixing the eggs and semen in a dry container. The water will stimulate the sperm to mix with the eggs. This method has the advantage that the semen will not be overly diluted, although sometimes there may be a delay entering into the egg mixture. This method can remove dirt attached to the egg, or semen, that helps to reduce the lack of oxygen in the hatching device. This method works well for fish with buoyant eggs, semi- buoyant eggs, and adhesive-demersal eggs in some species such as walking catfish and broadhead catfish.

5.6.4 Hormone stimulation

This method involves the injecting of hormones to stimulate the females with eggs in the resting phase of the development to progress their development to the final stage and ovulation. For the most part it is not necessary to inject hormone stimulation into male fish. However, if the fish produces only small amounts of semen it is possible to inject hormones to stimulate semen.

When the female fish has ovulated breeding can be done in one of two ways: 1) The broodstock are injected with hormones to stimulate spawning and can mix in the breeding pond, where the eggs are collected and removed to the hatchery and 2) Artificial propagation, where the fish are injected with a hormone to stimulate ovulation.

5.7 Hatching

Whether using artificial or natural methods eggs are moved to hatch into either a funnel type incubator, a hatching pond or similar. This will ensure that the eggs will develop normally and result in a high hatching rate.

5.7.1 Hatching equipment

Most hatching equipment used in Thailand are simple devices, and the characteristics of the hatching equipment can be divided into two groups:

Funnel type incubator

The funnel type indicator or hatching cone is traditionally called the Zoug jar. The funnel is a device designed for semi-submerged, floating eggs with a cone-shaped or cylindrical shape with a conical bottom. This is the most common type of incubator used in Thailand and has a water inlet and allows for an overflow. The pressure of the water will ensure the eggs will remain floating. The water flow is adjusted to retain the eggs up to two-thirds the height of the funnel's cone. Therefore, the strength of the water will depend on the capacity of the cone. For a 10-litre cone, the strength of the water should be between 0.5-1 litres per minute.

In addition to the Zoug jar hatch cone. There is also a McDonald type incubator that is used in some countries. This incubation cone is cylindrical in shape. A water pipe enters the top of the funnel and extends down to the bottom of the cone. When the water is turned on, the water will flow up and overflow through the top of the cone in a similar way to the Zoug jar cone.

Each species of fish has a different hatching time and requires different water quality therefore the equipment applied will depend on both the water quality and the type of eggs. Every incubation system will focus on the air supply to maintain a high dissolved oxygen (DO) level necessary for the normal development of the embryo. Hatching cones use the water to ensure the eggs are spread and not clumped. Some fish breeding farms in Thailand have modified this funnel hatchery by using air to make the eggs rise instead of using the water pressure. This method works well with a small hatch cone only. However, there is a risk of a reduced level of dissolved oxygen.

Hatching Pond

Hatching ponds are commonly used for hatching adhesive- demersal eggs and buoyant eggs. These eggs can be hatched directly, without any special equipment once there is sufficient oxygen supply and water flow. A concrete tank pond of any shape can be used; however, it is not as convenient for eggshell separation and the collection of fry.

Other hatching equipment

In addition to the two types of hatching equipment mentioned, many types of hatching equipment have been modified for use with specific species of fish for example incubation equipment such as using traffic cones for hatching eggs of Basa fish or using an aluminium tray as a hatching system of Nile tilapia (Figure 45) have been applied. However, the general principal still adheres which allows for the easy transfer of water. Trout and salmon eggs are commonly hatched in a flow-through water type incubator. Inside the rails, baskets made of specially woven nets are spaced apart from each other. The eggs that are incubated are packed in a basket and the water will flow from the top tray down to the bottom of the tray. This method of hatching is both space and water efficient. The subsequent larvae remain in the tray until they start eating and are then moved to the nursery.

The incubation of channel catfish using a flow- through water incubator differs slightly from hatching salmon with the addition of a propellor between each basket. The propellors are attached to the long axis that runs along the length of the rail. This axis rotates using electricity and turbines circulating the water and improving the flow. The larvae that hatch gather in the trough and when the larvae begin to eat, they will be moved into the nursery pond using a suction method.

Figure 45 Hatching equipment of Basa fish (left) and Nile tilapia (right)

5.7.2 Hatching methods

Hatching methods are determined based on the type of fish egg, i.e. buoyant, semi-buoyant and demersal eggs. The egg type will influence whether incubation ponds or hatching equipment are used and the method of care and management during and after hatching.

Pelagic eggs

The oil droplets present in these eggs cause them to float on the water surface, and after hatching, most larvae will remain swimming and floating upside down near the surface. Therefore, the hatching pond should have a sufficient surface area for the number of eggs being hatched and have an aeration system or regular water changes to ensure a high level of oxygen to maintains a good water quality. Climbing perch, sea bass, mackerel, and giant gourami, all have pelagic eggs.

Demersal eggs

This egg is dark and opaque and is denser than water. Upon spawning the eggs will sink to the bottom of the pond or attach to submerged material such as aquatic plants. A cement pond with a smooth bottom is the preferred type of hatching pond for the non-adhesive-demersal egg, or eggs that are attached to the bottom of the pond. For the adhesive-demersal egg, the material to which they attach is placed in the pond or the floating cage. A system to provide sufficient oxygen for the density of the eggs is required. This is sometimes a simple water flow through system.

Semi-Buoyant eggs

This egg is transparent, and without oil droplets and because it absorbs a lot of water the egg has a specific gravity similar to water. The equipment used for this type of hatch depends on the volume of eggs. Special incubation equipment, such as semi-buoyant egg incubators, are designed to allow the eggs to hatch in a cage made of glass, with a nylon screen, and use air bubbles to assist the eggs to float. Carp, Chinese carp and Rohu all have semi-buoyant eggs.

5.7.3 Environmental factors

There are several environmental factors that can impact the incubation of fish eggs such as the water quality, velocity and temperature, the amount of dissolved oxygen present and the presence of parasites etc.

The **quality and velocity of water** in the hatching equipment is important. If the currents are too strong they can damage the eggs or if they are too slow the eggs may sink to the bottom of the hatching equipment. The water used for hatching should be clear, of good quality, with a neutral pH and filtered to remove any sediment, suspensions and/or fish fry. The water system should flow through the eggs regularly and changes the water inside the device all the time. This water flow will allow the eggs to mix, have access to sufficient oxygen and release any waste dissolved in the water such as carbon dioxide and ammonia.

The normal development of an embryo involving the physiological processes and metabolism is closely related to **water temperature** (Table 20). The optimum temperature range for hatching should be between 22-27 °C (Table 21).

While fish are developing embryos, they need a very high levels of **dissolved oxygen**. The rate of oxygen intake increases steadily as they grow. he larvae of silver carp will need twice the oxygen intake, and this will continue to increase and to double this level again when the eggs are hatching. If the amount of dissolved oxygen in the egg is insufficient, they may not hatch or result in high levels of abnormal larvae. In general, the dissolved oxygen levels should be maintained at greater than 4-5 mg per litre.

Table 20 Hatching rate (percent) of silver carp and grass carp at different temperatures (Adapted from Zhu 1994).

Water Temperature (˚C)	18	20	22	24	25	26	27	28	29.5	30	30.5
Hatching time (hr.)	61	50	33	31	24	21	19	18	17	16	15.5

Table 21 Hatching rate (percent) of silver carp and grass carp at different temperatures (Adapted from Zhu 1994).

Water Temperature (˚C)	16	17	19	21	22	23	24	25	27	28	29	31	32
Hatching rate (%) of silver carp	0	10	35	59	78	85	93	90	87	78	53	20	5
Hatching rate (%) of grass carp	1	9	37	65	80	83	92	87	86	77	50	22	5

Ponds and hatching equipment that have not been sterilized or filtered and incubate aquatic animals in poor water quality are a breeding ground for **parasites and diseases** which will destroy fertilized eggs. In addition, the eggs within hatching ponds release waste and organic substances, including eggshells and unfertilized eggs, that promote bacteria, fungi, and protozoa to grow and spread to the fertilized eggs. To avoid this the water should be filtered until it is clear and clean, and the pond and equipment should be washed thoroughly with chlorine or malachite green to prevent the growth of bacteria and mould etc.

5.7.4 Fertilization and hatching rates

Early egg development is difficult to detect particularly between fertilized and unfertilized eggs. An embryo can be seen writhing inside a fertilized egg, once it is not opaque, after 3- 6 hours of fertilization. While the unfertilized will develop abnormally and have more turbid characteristics. Therefore, to successfully calculate the hatching rate of eggs it should be carried out 3- 6 hours after fertilization. The formula for calculating fertilization and hatching rates is as follows:

$$\text{Fert. rate (\%)} = \frac{\text{Fertilized eggs}}{\text{Total number of eggs}} \times 100$$

$$\text{Hatch rate (\%)} = \frac{\text{Hatching fry}}{\text{Fertilized eggs}} \times 100$$

In practice, however it is difficult to estimate the number of eggs that hatch, and it is the survival rate of fry to be brought to nursery is calculated instead. The fry that survives grow for 4-5 days by using the attached yolk sac.

$$\text{Survival rate (\%)} = \frac{\text{Number of fry stocked}}{\text{Fertilized eggs}} \times 100$$

5.8 Nursery

The rearing of larvae in the nursery is an important step in aquaculture. There are several forms of nurseries such as earthen ponds, cement ponds or cages, etc. The primary objective of the nursery is to increase the survival rate when compared to the low survival rate in nature. The nursery period is approximately 1 month with larvae selected based on their size.

5.8.1 Nursing using supplementary food

Fry that have just hatched from the egg will have a yolk sac around the abdomen. The fry will rely on the food from the yolk sac to live for 1-2 days depending on the species of fish. When the fry has run out of food from the yolk sac the farmer must provide the food for the fry. If there is not enough food supplied during this period it will affect the growth and survival rates.

Carnivorous fish larvae, such as climbing perch, will need live food, therefore, water flea or brine shrimp (*Artemia* sp.) needs to be prepared for fish larvae. The fish larvae will be fed with live food over a period of around 10-20 days depending on the species.

Nursing of omnivorous fish larvae, such as common carp, rohu, silver barb, etc., requires supplementary feeding when the fish have used food from the yolk sac. The most popular supplement feed used to be boiled eggs. But nowadays using small powdered food which has a more complete nutritional value are fed to the fish over a period of 10- 15 days depending on the fish species. The systems employed to nuse fry depend on the type of feed used i.e. natural or supplimentary feed.

Feed

The supplementary food used to feed the fry initially depends on the developmental stage of the fry. At 10 days the fry will need special food as their egg sac supply runs out. As the receptor organs of the fry are not well developed looking for food is more difficult. The fry swim continuously with an open mouth in search for food. For this reason, the initial

food of the fry should be small enough to fit into the mouth of the fry.
The food needs to be plentiful and reflect the nutritional needs of the fry. Initially when they begin to eat various food types are suitable for the fish for example plankton, especially rotifers. When the larvae begin to grow, they can eat larger food such as copepods, red mites and/or other mixed food.
Live feed includes rotifers and water flea. They in turn consume *Chlorella* spp. which can easily be cultivated by adding fertilizer to the fishpond.

Chicken eggs are a **supplementary food** of high nutritional value that is suitable for the rearing of larvae. Both the egg yolks and whites are used but they need to be pre-ripening to destroy the avidin; Avidin can inhibit the growth of the larvae. Using only the egg yolks will cause fish to eat less food as the yolks themselves provide very high energy. However, the protein level that is obtained is not sufficient for fish growth. Eggs are found to contain only small amounts of vitamins when dissolved in water, especially vitamin C, therefore, if raising fish with an egg-based feed over a long time it is necessary to include vitamins and calcium in the diet

Fish cultured with live food is effective, however the method of preparing food is often quite complicated and time and labour intensive. In addition, it also depends on weather conditions. **Artificial feed** produced for fish food, must contain all the nutrients required by the fish larvae which are easily digested and absorbed. Food must be small, and consideration taken for water absorption. Lastly, both the smell and taste must be palatable to the fish.

Feeding

Once the provision of feed is required, water fleas, chlorella and boiled eggs are provided depending on the species of fish. As the fish grows this feed is supplemented with rice bran and fishmeal. The protein requirement of the feed depends on the species, for example pangasius larvae require protein levels of 25%, snakehead fish 42% and common carp 31-38% protein etc.
The quantity of feed provided for small fish larvae is generally not proportional to their body weight. However, it must be in sufficient quantities and size that is can easily be found by the larvae, for example 6- 10 rotifers per millilitre is provided during the nursing of sea bass. The provision of supplementary food, such as boiled eggs, is little and often and therefore more time must be allocated to allow for regular feeding. As the fish develop each new food type should be gradually introduced through reducing the initial food and adding small amouts of the new feed to ensure the fish are eating sufficeint protein and nutrients for their diet (Table 22, Table 23)..

Table 22 The feeding scheme for the sand goby showing the introduction of new feed at the Pathum Thani Aquaculture Development Station, Thailand (adapted from Cho et al. 1985)

Day	0	1	2	3	4	5	6	7…	…19	20	21...	…30
Boiled egg		■	■	■	■	■	■	■				
Rotifer							■	■	■	■	■	■
Water flea										■	■	■

Table 23 The feeding regime for marine species of fish in Japan (adapted from Cho et al. 1985)

Day	0	5	10	20	30	40	50
Size (mm.)	3.4	4.2	7.3	9.8	10		30
Rotifer	■	■	■	■	■		
Copepod					■	■	
Artemia					■	■	
Fresh Fish					■	■	■

5.8.2 Nursing Ponds

There are three types of ponds regularly used as nursery ponds namely, cages, earthen and cement ponds. Nursing of fry using supplemental food can be done in both concrete and soil ponds. The concrete pond has an advantage which allows for the ease of fish care however, some species such as pangasius, cyprinid should be nursed in a soil pond to reduce costs. These earthen ponds will have both supplementary food and natural food, causing the fry to grow faster. Natural food, including both plants, and animals, that inhabit nursing pond are a good food source for fish larvae due to their high nutritional value and varying types and sizes available.

Earthen ponds

Earthen ponds tend to be about 200 m^2 with a water depth of 1 meter. This will facility the feeding of 1- 2 small centimetre tilapia larvae at densities of approximately 250 fish per square meter feed or about 50,000 fish at any one time. The pond is prepared 1 week in advance of larvae and fertilizer is used to create and encourage the growth of natural food. During the nursery period the abundance of natural food present can be assessed based on the colour of the water. Supplementary food, e.g. fine bran or molasses mixed with fish meal, can be added as need to accelerate growth.

Cement ponds

A cement tank, either square or round, can be used as a nursery pond. The surface area of which must be at least 10 m^2 with a water depth of about 1 meter. Fry are cultured here at a density of about 300 fish per square meter. The use of aeration systems is required and the water in about half the pond is exchanged once a week. As there is no natural food available within theses ponds Feeding should take place 3 times a day.

Cages

Cages can be made of nylon mesh or green net. While the size of the cage reflects the area of the pond that will be hanging, generally, cages of 3x3x2 cubic meters are used for nurseries. Densities can be as high as 300-500 fish per square meter or about 3,000-5,000 fish per cage depending on fish species. The advantages of cages are that they are easier to care for than nursing within earthen or cement ponds. The food supplied needs to be highly nutritious i.e. 30-40 % protein or boiled egg yolks.

There are several steps to consider when you are preparing a pond as a nursery:

Removal of Predators

Larvae that are released into the pond are small and very fragile. Therefore, it is necessary to remove all the potential pests and predators of fish larvae, including various known fish and invertebrates, before releasing the fish. Eliminating the use of toxic drugs in the ponds, which can leave residues in the water including seed cake, sodium cyanide etc.

Addition of lime

There are many forms of lime which can be used, including limestone or marl ($CaCO_3$ or $CaMg(CO_3)_2$), quick lime (CaO or $Ca(OH)_2$). While the application of lime has the primary purpose of increasing the pH of the soil, it also increases the availability of calcium and magnesium. Where fertilizers are added to the pond then the addition of lime will improve the absorption of various nutrients by the larvae. It is not necessary to add lime to ponds where no fertilizer is being added. In addition, hydrated lime helps with the decomposition of the organic matter at the bottom of ponds thus eliminating germs and potential pests.

Generally, 60 kilograms of lime is applied per 1,600m^2 (1 rai) of pond space. The lime is applied through spreading over a damp or wet pond bottom. Where the land is acidic, the amount of lime used will increase in proportion to the acidity of the pond.

Fertilizer

Organic fertilizer is commonly applied to earth ponds and can be in the form of manure, compost, or green manure. The fertilizer is placed on the edge of the pond rather than sown all over the pond, because when the fertilizer decomposes it will reduce the oxygen levels in the pond. If placed as a pile on the side, degradation and subsequent reduced oxygen levels will only occur at one point, while the nutrients released will be dispersed throughout the pond. Manure should be dried before being put in the pond to get rid of ammonia which will be harmful to the fish.

Natural food sources, both plants, and animals, that inhabit nursing pond, will multiply in the pond with the addition of fertilizer which may be either organic or chemical fertilizer. Organic fertilizer is more popular as the only effect is the reduction in oxygen levels. While the application of fertilizer in soil ponds is more effective than concrete ponds due to the presence of these natural communities.

Stocking densities

The density rate of fry in nursery ponds will affect the growth and production of fish larvae. An optimal density rate will allow the fry to grow quickly and produce high yields. In addition, if the food conversion ratio is low, the density rate of fry within a nursery is difficult to determine.

Concrete nursery ponds that increase water levels daily, fertilize the pond, provide supplementary food and aeration at night can stock fry to densities of 1,000-2,000 fish per square meter. While in small ponds, with stagnant water systems, where fertilizers and supplementary food are provided the density level drops to 400-600 larvae per square meter. Where no supplimantery feeding and only fertilizer is added then the density levels drop further to 150-300 larvae per square meter.

Water management

In the nursery pond, the **water level** should not be very high. In general, the water level at the time of raising the fish should be around 50 centimetres. At the beginning of nursing, the water starts to change property, so the water level will increase. It may be necessary to absorb/remove excretion and food waste every day particularly where there are high stocking densities to ensure the water quality remains high, particularly in concrete ponds where the feeding rate is high. The water should be monitored to ensure the water is exchanged when needed following the initial nursing stage.

The **dissolved oxygen** level in the water needs to be at minimum 3 millilitres per litre. If it is found that the dissolved oxygen in the water is low, then exchanging the water will improve the water quality and dissolved oxygen levels, while also reducing the ammonium levels.

Several animals **predate** on fry including both the larvae and adults of vertebrates, such as various fish, frogs, snakes, turtles, and soft-shelled turtle, etc. , and invertebrates, such as backswimmer species. There are also dragonfly larvae, scorpions and garden insects, etc. These animals can have severe impacts on nurseries particularly in earthen ponds, while are rarely a factor in concrete. They are eliminated using dipterex at the rate of 0.5 grams per cubic meter. Dipterex will disintegrate within 3-5 days.

5.8.3 Collection and transportation

Catching fry for sale or for further rearing in earthen ponds should be when the fry that are at least 1-2 centimetres, or at a healthy age where they can survive and feed themselves.

However, catching and transporting fry still provides a risk of death or weakness because the fry are still relatively small and fragile.

Catching fry

Farmers should be careful catching fry to not cause injury. Draining the water to one third of the depth of the pond is the first step or if it is a cage nursery, the net may be gathered. The fry are encouraged together in one corner of the floating cage, then a the container is used to scoop out the fry. Nets with a pore size smaller than the fry are used to gather fry in concrete ponds. It is more difficult to catch and collecting from a soil pit nursery, however nets are also applied here on a clear morning.

Fish preparation

Fry collected are placed into an air storage pond with no feed for at least 12 hours prior to transport in order to reduce excretion while in transport. The conveyor selects the size of the fry needed using plastic punched with holes which vary between 0.3 to 10 millimetres. The fry are then dipped or immersed in chemicals, such as formalin 15 parts per million, potassium permanganate 2- 3 parts per million and acriflavin parts 1 part per million, to eliminate diseases and parasites attached to the fish.

Containers for transportation

There are a variety of transportation containers used, such as fiberglass buckets, wooden buckets, metal buckets, pick-up containers, water tanks, and clay pots, etc. The choice of container depends on the size of the fish, density, aeration, time, and the transport distance. In most cases, transporting short distances the conveyor may choose to use open containers such as plastic tanks however, for long-distance transportation > 200 km or > 12 hours or require air transport they will need to be contained in containers that are constantly aired,. Plastic bags are often used, 20 × 30 inches size, which contain 3- 5 litres of water, are compressed with oxygen and packed into foam boxes or plastic buckets with ice bags to control the temperature in the box.

Weighing, measuring, and counting

Weighing is largely only applied to large fry. The average weight of a fish larvae is calculated by sampling a few larvae in a water container and weighing it, then counting the number of fry present. This is randomly repeated to calculate the average weight of one fish larva.

Measuring is carried out on small or lightweight fish, by using a net to scoop out the water, then use a measuring spoon to scoop out the larvae. The fish are counted on the spoon and the individual weight calculated. The measurement is repeated randomly several times to get an average number of fry in a spoon. This allows the conveyor to pack the larvae in the bag with the required number of fry, based on the number of spoons.

Where the fry are very small and lilghtlweight and to ensure no damage is carried out density levels are estimated. Containers with the same size and volume of water are used to count the number of larvae present. The visual comparison between containers will allow the density to be determined. This method is often close to the true value. However, there may be errors, particularly if the size of the larvae are different in the pond.

Packing for transportation

Fry are packed in triple layered plastic bag to prevent water leakage (Figure 46). The plastic bags, filled with water from the same source as the reservoir, are tightly stacked. The density of the fry depends on the type and size of the fry, the size of the bag, the oxygen content, temperature, distance, and length of transportation. For example, if the fry are small, the temperature is lowered and the distance is not very far then the densities can be very high.

Figure 46 Fry packed and ready for transportation (Pornthep Niamphitak)

Chemicals in transportation

Transportation over long distances at high densities and in containers with limited space can cause the fry to be stressed, easily shocked, and injured. Some chemicals can be used in transportation such as salt and anaesthetic to reduce these impacts. Salt helps to maintain the balance of minerals and dissolving a small amount of salt into the water used in transportation will reduce the osmotic pressure causing the osmotic pressure between the fish's blood and water to be similar and this can reduce stress. There are many types of anaesthetic that can be used in transportation. Alternating medication will reduce the body's metabolic rate, reduce oxygen consumption, and reduce waste. However, anaesthetic should be used with caution. There are many types of anaesthetic and some may have side effects, which are harmful to the health of the fish.

Vehicles used for transportation

Transport can be carried out via airplanes, automobiles, air- conditioned vehicles, pick- up trucks, and small trucks. The conveyor should be fast and have a temperature-controlled tank room or use various materials to control the temperature which helps to reduce the metabolic rate, causing the fry to have a high survival rate. In addition, where possible transportation should take place in the morning or in the evening when temperatures are lower and there is little sunlight.

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6: Feed and Feeding

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In aquaculture, feed plays an important role as it accounts for a very high proportion of production cost (60-80%). Therefore, saving on feed costs significantly increases profits. There are several ways for saving on feed costs such as reducing the overall spend on feed or minimising the amount of feed lost during feeding. Reducing feed cost is associated with selecting high quality nutritious ingredients for formulated diets while reducing the amount of feed consumed requires an understanding of the nutritional requirement needed to balance the diet. This chapter explores both 1) Feed composition and key ingredients (protein, lipid, carbohydrate and vitamin) for the nutritional requirements of aquatic animals; and 2) Feed formulation and feeding including identification of the main ingredients required for formulation of a diet and the stability and storage of feed.

6.1 Feed composition & ingredients

6.1.1 Nutrients

Proteins

Protein has a very complex structure and it is the main organic elements of every aquatic animal, accounting for 60-75% of the dry weight of the body. The chemical composition of protein contains carbon (50-55%), oxygen (22-26%), nitrogen (12-19%), hydrogen (6-8%), and sulphur (0-2%). Although protein varies greatly in structure, function, and chemical composition, once broken down or hydrolysed the basic units remaining are amino acids (AAs).

Protein function:

The main function of protein is to build and repair body tissues. Protein is digested or hydrolysed from food and releases free AAs. In the digestive tract, the AAs are absorbed into the bloodstream and travel to the cells of all tissues and organs, where they participate in protein biosynthesis, facilitating the growth, reproduction, and maintenance of the body. Therefore, if the quality and quantity of protein in the feed does not meet the requirement of the fish, it will result in a slower growth rate or potentially weight loss. Protein is the most expensive part of all fish diets. When an adequate level of fats and carbohydrates (energy) are present in the diet, the protein is solely used for fish growth. However, if the amount of protein in the feed exceeds the demand of animal, the excess will be converted into energy. Similarly, if the ratio of fats and carbohydrates is inappropriate then a larger proportion of protein will be used as energy. Conversely, when the feeds contain low protein content, growth, health, and reproductive capacity will be negatively affected.

Protein requirements:

The dietary protein level required for optimum growth of aquatic animals mainly depends on species, their life stages and culturing systems. The protein requirements for aquatic animals are often greater than that for terrestrial animals (25-55%). For example, protein levels in aquaculture feeds generally 30-35% for shrimp, 28-32% for catfish, 35-40% for tilapia, 38-42% for hybrid striped bass, and 40-45% for trout and other marine finfish, while it ranges between 30-60% for crustaceans. Herbivorous fish and omnivorous fish generally require lower protein level in their diets than carnivorous fish. Fish cultured in high-density systems need higher protein requirement compared to those reared in the low-density culture. In addition, an early life stage fish generally requires a higher protein diet. Furthermore, the level of protein required is adjustable depending on a number of factors such as water temperature and water quality, as well as the feeding rates of the species.

Amino Acids requirement:

AAs play a central role as the building blocks of proteins, hormones, enzymes, and as the intermediates in metabolism. Dietary AAs are crucial for fish as energy substrates, for endogenous protein synthesis and regulating metabolic pathways. AAs participate in the process of creating energy directly or in the accumulation of glycogen or lipid. Recently, more attention has been paid to the function of AAs to modulate key metabolic pathways thus affecting immune response, health, and reproduction, etc. Among of 200 AAs that occur in nature, only about 20 AAs are common. They are divided into two groups as non-essential and essential AAs. Non-essential amino acids (Alanine, Glycine, Serine, Tyrosine, Proline, Cysteine, Cystine) can be synthesised from other compound, while essential AAs (methionine, arginine, threonine, tryptophan, histidine, isoleucine, lysine, leucine, valine, and phenylalanine) cannot synthesised, thus they must be supplied as part of their diet.

Of the 10 amino acids mentioned above, methionine and phenylalanine are closely related to non-essential amino acids, cystine and tyrosine, respectively. When cystine and tyrosine are present in the feed, the need for methionine and phenylalanine will subsequently decrease. In fact, Cystine can replace 50% of the methionine requirement.

Fish are not able to store free AAs. Therefore, if an AA is not used immediately for protein synthesis, it will be converted into another AA or be utilized as energy. The imbalance of AAs in diet can result in reduction of the efficiency of protein utilisation. There are several factors can affect the protein requirements of animals including:

Feed energy: aquatic animals can use protein in feed as metabolic energy. The requirement of protein as a source of energy is likely to decrease when the lipid and carbohydrates (alternative cheaper energy sources) increase in the feed. If the amount of energy (lipid and carbohydrates) is too high in feed, feed consumption of aquatic animals will be negatively affected because feeding activities of fish reduce energy demand are met. Therefore, the optimal protein in feed for aquatic animals is influenced by the optimal ratio of protein and energy.

The optimal protein and energy ratio (P/E) for aquatic animals varies with species, but it is usually greater than 20 mg/kJ due to high protein requirements. The P/E ratio also varies with environmental factors such as the rate of water flow, temperature, feed composition.

Feed quality: The optimal protein requirement is also influenced by the feed composition. Factors such as the AAs profiles, protein digestibility and the ratio of other energy sources such as lipids and carbohydrates in the diet can influence the protein requirement of fish.

Development stages: fish grow faster during their early development stage; therefore, younger fish normally require a higher level of protein in the diet than large and mature one. For example, tilapia with sizes of 1-5 g, 5-25 g, > 25 g require 30-40%, 25-30% and 20-25% crude protein (CP), respectively. During the breeding stage, the protein requirements of aquatic animals are higher than during the growth stage as they need a high amount of protein for developing the gonads. For instance, the protein requirement of the giant freshwater shrimp during the growth stage is about 25-28% CP, while it is more than 40% CP at the sexual maturity stage.

Environment: Environmental factors such as temperature, light, salinity, dissolved oxygen, pH can affect the protein requirement of aquatic animals. As the temperature rises within optimal range, fish growth increases resulting in an increased protein demand.

Feeding rate: The quantity of feed is an important factor that can affect fish performance. When fish are fed a limited amount of feed, the protein level in the feed may need to be increased. If the feeding rate is close to demand of fish, the feed conversion ratio will be high. On the other hand, an excess of feeding can result in poor efficiency of feed conversion due to feed lost and reduced digestibility.

Lipids

Lipids are one of the basic biochemical components of plants and animals which play an important role as the source of energy and necessary for the growth and development of aquatic animals. Lipids in feed also act as transporters of oil-soluble vitamins and sterols. Phospholipid and sterol-ester, found in lipids, are involved in cell biosynthesis.

Lipids are high-energy nutrients that can be utilised to partially substitute for protein in aquaculture feeds. Lipids have about double the energy density compared to proteins and carbohydrates and it typically makes up about 7-15% of fish diets. It is supplying the essential fatty acids and serve as transporters for fat soluble vitamins.

Lipid plays an important role in improving the quality of feed for aquaculture. Previous studies have shown that lipids significantly influence on the growth of animals, especially on the larval and breeding stages. At the maturation stage, appropriate lipid sources in feed can improve the reproduction as well as the quality of the larva, juvenile and fingerlings.

The functions of lipids:

Energy sources:

Lipids are the best source of energy for aquatic animals. The proper intake of lipids can reduce the level of protein required in feed. Triglyceride is the main ingredient of lipids involved in the energy-generating oxidation in aquatic animals. Energy in feed is not used directly, it is usually stored as glycogen and fat. Large quantities of lipids are stored in the liver and muscles of fish or in hepatopancreas of crustaceans. In addition, lipids are stored in the form of fat tissue surrounding the intestines of fish such as carp, tilapia, and forming fat leaves in catfish.

Enzyme activation:

Lipids, especially phospholipids, have the ability to activate enzymes. For example, phosphatidyl choline has the ability to activate the glucose 6 phosphatase enzyme, Adenosine Triphosphatase (ATPase). Lipids are the main component of many hormones including steroids. In addition, some polyunsaturated fatty acids (PUFA) are the precursors of prostaglandin, a 5-ring fatty acid, in fish and shrimp, where very small quantities can act like hormones.

Cell membrane structure:

Polarized lipids or phospholipids have a very important role in nutrition because they are part of the structure of all cell membranes.

Absorption of other lipids:

Phospholipids play a vital role in lipid transport and absorption, which are involved in metabolic processes in the organism. Phospholipids act as emulsifiers that help fatty acids, bile salts and fat-soluble substances attach to tiny micelle particles. Due to the characteristic of having two polarizing heads: hydrophobic and hydrophilic, the phospholipids located outside the micelle granules attach to lipid hydrolysate products. The transport of micelle particles through the cell membrane is due to the association of micelle particles with two phospholipid layers of the basal membrane so the lipid hydrolysis products are transferred through the cell membrane and absorbed into the lymphatic system.

Transportation:

Lipids are solvents that dissolve oil-soluble vitamin A, D, E, K. Therefore, any uptake and transport of lipids in the body will also include the lipid soluble substances.

Lipid requirements:

The lipid requirement of aquatic animals is determined based on their requirement for energy, essential fatty acid, phospholipid and cholesterol. Energy requirements of fish and shrimp are lower than terrestrial animals and they can use protein for energy. Previous research showed that the survival and growth rate was maximum when shrimp fed diet with lipid levels ranged from 5-8%. For fish, lipid content varies by species, but the recommended range is 6-10% (Table 24).

Lipid requirements depends greatly on the quality of ingredients and crude protein level in feed. The recommended protein to lipid ratio for shrimp and fish is 6-7: 1.

Fatty acids:

Simple lipids include fatty acids and triacylglycerols. The difference between lipid types is based on the composition and ratio of fatty acids. There are more than 100 different fatty acids. Fatty acids rarely exist in the free or ionized form called acylate. The more common type is esterified as a combination of lipids.

Fatty acids can be saturated fatty acids (no double bonds), polyunsaturated fatty acids (>2 double bonds), or highly unsaturated fatty acids (>4 double bonds). Fish typically require fatty acids from the omega 3 and 6 (n-3 and n-6) families.

Biosynthesis of fatty acids:

Aquatic animals have the ability to biosynthesize some fatty acids such as unsaturated fatty acids from acetate, and polyunsaturated fatty acids to saturated fatty acids. Unlike plants, aquatic animals lack the desaturated enzyme, thus it is only possible to add or increase the number of double bonds to the CO-OH base as opposed to the methyl radical (CH_3), so unsaturated fatty acids cannot be synthesized without precursors in the food.

Essential fatty acid requirement:

When considering the essential fatty acids (EFAs), it is often based on the fatty acid composition of the natural food and the fatty acid component in the carcass of aquatic animals. The basic food group of the marine ecosystem is microalgae, in which the lipid growth stage accounts for 20% (dry weight), of which 50% is comprised of the unsaturated high-molecular n-3 fatty acid group (n-3) and PUFA such as 20:5n-3, and 22:6n-3. Microalgae are an important food for crustaceans, zooplankton, and groups of herbivorous fish. Due to the inability of aquatic animals to synthesize these fatty acids, the provision of these fatty acids in food for marine aquaculture is necessary. For freshwater algae, the level of n-6 fatty acids is richer than within seaweeds. Similarly, freshwater fish have more 18 carbon fatty acids and n-6 PUFA than marine fish.

Previous studies have shown that aquatic animals require n-3 fatty acid and 1-2% dietary 18:3n-3. Requirements for longer-chain fatty acids (HUFA) such as 20:n-3, 22:5n-3, and 22:6n-3 are lower, at about 0.5%. In general, aquatic animals require the supply of both n-3 PUFA and n-6 PUFA fatty acids, but marine groups require more n-3, whereas freshwater species need more n-6. The ratio of n-3/n-6 varies by species and source of fatty acids provided. The n-3 fatty acid group functions primarily to synthesize long-chain fatty acids, while the n-6 group is used as a source of energy and storage.

In larval stage, lipids are important because they provide the essential fatty acids that is vital for larval development, metabolism, physiology, and body building. Fatty acid requirement is higher in larval stages than in later stage. In addition, lipids and essential fatty acids are essential during the metamorphosis of nauplii, zoea, mysis, postlarvae of giant tiger shrimp.

Signs of essential fatty acid deficiency include reducing growth and food efficiency, increasing mortality rate, erosion of the caudal fin, liver degeneration (identified through enlargement and/or colour), reducing reproduction rates such as lower hatching rate and lower survival rate of larvae and fry).

Table 24 Lipid requirement of several aquatic animals

Species	Lipid source	Lipid level	Optimal level	Author
Homarus americanus	Fish liver oil	1, 5, 10, 15	5%	Castell and Covey (1975)
Procambarus acutus	Fish oil	0,3, 6, 9, 12, 15	9% or higher	Davis and Robinson (1986)
Marsupenaeus japonicus	Fish liver oil + soybean oil	3, 6, 9, 12	6%	Deshimaru and *et al.* (1979)
Macrobrachium rosenbergii	Fish liver oil + corn oil (1:1)	0, 2, 4, 6, 8, 10, 12	6%	Sheen and Abramo (1991)
Penaeus monodon	Squid oil, fish oil	-	6-7.5%	D'Abramo (1997)

Carbohydrates

Carbohydrates such as starches and sugars are the cheapest sources of energy for aquatic animals. Although carbohydrates are not considered as essential nutrient factor, but it is used frequently in aquaculture diets to reduce feed costs and for binding purpose during feed manufacturing. Dietary starches are also important in producing floating feeds.

In fish, carbohydrates are stored as glycogen that can be mobilised to satisfy energy demands. Fish can use up to about 20% of dietary carbohydrates. Carbohydrate digestion varies greatly between species and ingredient quality. The metabolic energy (ME) conversion from carbohydrate of aquatic animals varies from 0 kcal/g (cellulose) to 3.8 kcal/g (single sugar). Carbohydrates make up over 75% of plants, while in animals they are present in small quantity and exist primarily as glycogen.

Carbohydrates (Glucids) contain Carbon, Hydrogen and Oxygen with a general formula of $(CH_2O)n$ or $Cx(H_2O)y$. Carbohydrates are found in plants which are divided into two main groups: the sugar group and the sugar-free group:

The sugar group includes monosaccharides (simple sugars): such as glucose, galactose, mannose, fructose and oligosaccharides (sugars): which include sucrose, lactose, maltose etc. This group is not considered as an essential ingredient in aquatic animal feed.

In contrast, the sugar-free group such as starch that plays crucial role in aquatic feed. This group includes homoglycan starch, dextrin, glycogen, cellulose and heteroglycans: pectin, hemicellulose.

Carbohydrates are divided into 2 main groups in terms of nutritional value. These are non-protein derivatives (NFE: Nitrogen Free Extracts) and crude fibre (CF). NFE are mainly starch and sugar, which are both easily digested and absorbed in the digestive tract of fish and shrimp. However, fibre is difficult to digest due to lack of enzymes to hydrolyse them.

Starch is a glucosan (glutan) which is abundant in nature. It acts as a reserve food supply in plants. Nuts contain about 70% starch while tubers have 30% of starch. Starch is present in plant cells in the form of starch particles including amylose (20-30%) and amylopectin (70-80%).

Amylose consists of non-branched chain (a-1,4) glucose units, while amylopectin consists of the main chain (a-1,4) and horizontal branches (a-1,6).

Dextrin is an intermediate product of starch and glycogen hydrolysis. It is often used as a binder in aquafeeds. In the study of carbohydrate use for shrimp and fish, dextrin is regularly used as a carbohydrate source.

Glycogen is a form of carbohydrate storage found in the liver and muscles of aquatic animals. Glycogen is analogous to starch. It has a high molecular weight contains between 5,000 to 25,000 glucose units.

Cellulose: As a glucosan, there is a 1-4 b-glucose binding structure with about 8,000 b-glucose molecules joined together. Cellulose is a key component of the plant cell wall. This is an important source of feed ingredients for aquatic animals.

Chitin and **Chitosan**: Chitin is the polymer of N-acetyl glucosamine units while chitosan is made up of glucosamine units. Chitin is very common in lower animal groups, especially in crustaceans. This ingredient is often found in shrimp meal and it affects the feed digestibility, particularly digestion of protein in aquatic animals.

Importance of carbohydrate in feed:

Carbohydrates are one of the body's structural components like glycoproteins, present in cell membranes. They are the main source of energy for the entire body's living activities. In the diet, when carbohydrates increase, the breakdown of lipid and protein in the body will decrease as the energy source will be largely provided by carbohydrates. Therefore, apart from proteins and lipids, carbohydrates are considered as a source of energy.

Carbohydrate digestion:

Starch is known as the main source of energy in aquaculture. However,

the digestion of carbohydrates by aquatic animals is inferior to that of terrestrial animals. The digestibility of carbohydrates varies according to a number of factors including species and the nature of the carbohydrate ingredients. Subsequently, the preferred source of energy for the metabolism of shrimp and fish is protein and lipid rather than carbohydrates.

The digestion rates of starch for freshwater and warm water fish are superior in comparison to marine fish and cold-water fish (Table 25). This difference is related to the activity of the enzyme amylase. Carbohydrate digestion rate of carp are 10-30 times higher than that of salmon. Herbivorous fish have a more effective carbohydrate digestive enzyme than carnivorous fish.

Fish and most aquatic animals do not have the b-1.4 hydrolytic enzymes, so the digestion of cellulose is almost negligible. Several researchers suggested that the intestinal microbiota of some fish can hydrolyse cellulose in fibre. However, the structure of digestive tract of these fish show that these bacteria have an exogenous origin.

Chitin, sourced from artemia and daphnia and other crustaceans is considered an important nutrient for carnivorous species, especially in the larvae and fry stage. The endogenous enzyme chitinase, is capable of digesting chitin. The ability to digest chitin is also found in crustaceans.

Carbohydrate digestion is highly dependent on daily feed intake and the cellulose ratio in feed. When increasing the daily feed intake, aquatic animals tend to reduce their digestion rates due to the speed at which the food travels through the digestive tract, so the ability to digest food reduced.

Table 25 Carbohydrate digestion by fish

Species	Carbohydrate source	% in diet	% Digestibility	Author
Rainbow trout	Glucose	20 60	99.3 99.5	Singh & Nose (1967)
	Dextrin	20 60	77.2 45.5	Singh & Nose (1967)
	Cooked Potato starch	20 60	69.2 26.1	Singh & Nose (1967)
	Cooked starch	11.5 40.2	90 48.2	Singh & Nose (1967)
Carp	Potato starch	-	55	Chiou & Ogino, 1975.
	Cooked Potato starch	-	85	Chiou & Ogino,1975.
Catfish	Corn starch	12.5 25 50	72.8 60.9 55.1	Saad (1989)
	Cooked corn starch	12.5 25 50	83.1 78.3 66.5	Saad (1989)

Carbohydrate efficiency:

The effect of using different carbohydrate sources depends on the molecular weight and fish species. For salmon, digestibility decreased in the order of glucose, maltose, dextrin, cooked starch and potato starch. The growth rate of fish decreases as an increase of the carbohydrate molecular weight. In contrast, for American catfish, the efficiency of using starch and dextrin is higher than that of double and simple sugars. The digestibility of the three carbohydrate sources were compared to carp the most digestible was starch, followed by dextrin with glucose being the least. The digestibility of the three carbohydrate sources in carp species are starch, following by dextrin, and glucose. The carbohydrate digestion of some fish species is shown in Table 25. Black tiger shrimp can use starch more effective than glucose.

Aquatic animals have the ability to digest glucose, but the use of glucose is very poor. The poor carbohydrate utilization varies by aquatic animals can be explained by the high and excessive accumulation of glucose in the blood. This problem is considered to result from a lack of insulin needed for normal metabolic processes of fish. In addition, when the fish uses a high amount of carbohydrates, the blood glucose level increases, result in reducing growth.

Previous studies showed that when fish are fasting, glycogen content in liver, and blood glucose remain unchanged, meanwhile, lipid (cellular tissue) is used as a source of energy through the glucogenesis pathway (synthesizing glucose from other substances). However, some fish species can use glycogen for energy before using lipids, such as tilapia (*O. mossambicus*).

Carbohydrate requirement:

The ability to utilise carbohydrates of aquatic animals varies. Omnivores and herbivorous have a greater ability to utilise carbohydrates than carnivorous animals. Carbohydrate in the diet of marine fish averages about 20% while this is higher in freshwater fish diets.

Some fish and shrimp do not need carbohydrates because they can synthesise them through glucose metabolism (gluconeogenesis) or they can satisfy their energy needs from lipid and protein.

Starch, dextrin and cellulose are commonly used in aquaculture feed, while the use of simple sugars such as glucose, sucrose is not economical. Although carbohydrates are considered as unnecessary nutrients, the addition of carbohydrates into aquaculture feeds can reduce feed costs, reduce amount of protein as a source of energy, or increase feed stability in water (binder in feed) and decrease the level of smudging, dusting of food (adhesive components together). In processing technology, carbohydrates are considered an important binder.

Vitamins

Vitamins are organic compounds, which are often not synthesized by fish. They are a necessary dietary component to support growth and health of fish. The vitamins are classified as water-soluble and fat-soluble. Both types of vitamins play an important role in the nutritional composition of aquatic animals. Compared with the main dietary nutrient components such as proteins, lipids and carbohydrates, vitamins account for only 1-2% of feed. However, they have a crucial role in the body's metabolism and the cost of vitamins can be as much as 15% of the diet.

Most vitamins act as co-enzymes or an enzyme supporting agent that performs biochemical reactions within the organism. Vitamins can act as agents for oxidation, converting electrons from organic compounds to receptors. Co-enzymes are required by enzymes to catalyse a specific reaction. Vitamins as co-enzymes assist in converting a substrate to an end-product, for example in the formation of red blood cells and nerve cells and precursors of hormones.

Research has indicated that aquatic animals do not have the ability or a limited ability to synthesise vitamins to meet their need. Therefore, vitamins supplementation in the diets for aquatic animals is necessary.

Previous research showed the inadequate of dietary vitamins results in reducing growth, lower survival rates, poor resilience to environmental fluctuations and more susceptible to diseases in cultured species. Vitamin deficiency in aquatic animals have shown pathological symptoms such as deformity, haemorrhage, cracked skulls in fish and black death syndrome in shrimp.

The vitamin requirements are influenced by many factors such as different species, sizes and development stages or environmental factors. It is also affected by the interaction with other nutritional feed components and most notably as processing and storage of vitamins.

Factors effecting vitamins:

Processing and storage

Most vitamins are sensitive with processing and storage conditions. The increasing in heat during the pelleting stage often breaks down vitamin C, vitamin B12 and pyridoxine. Maintaining appropriate temperatures during processing, and/or mixing the "lipid-vitamin" solution and spray the outer surface of the pellet after drying feed can reduce vitamin loss.

Some vitamins that are sensitive to sunlight and UV light, such as vitamin B12 or vitamin E, are lost when the feed is exposed to direct sunlight and therefore should be stored out of sunlight. In addition, fat-soluble vitamins such as vitamins A, D, E, and K will degenerate if food processing conditions such as humidity and high temperature are not controlled.

Ability to synthesize vitamins

Aquatic animals have a limited ability to synthesize vitamins, thus a sufficient amount of vitamins needs to be incorporated into feed. The intestinal microorganisms of some fish, such as carp, tilapia, and salmon, have the ability to produce vitamin B12 complex. However, this biosynthesis may be limited where there is an antibiotic present in the feed. The warm water fish can synthesise vitamins better than cold water fish.

Culturing conditions

Culturing condition influences greatly on the vitamin requirement of aquatic animals. In the extensive or improved extensive farming, no need to supply vitamins because fish and shrimps can synthesis vitamins from natural food. While in the semi-intensive, intensive and cage culture systems, animals mainly rely on formulated diets. Thus, it is necessary to provide adequate vitamins in the diets.

Physiological conditions

Vitamin requirements of aquatic animals vary according to the stages of their life cycle. During their larval stage, fish and shrimp need more vitamin C than the adult and broodstock stages. For example, at the larvae stage of giant freshwater shrimp, it is necessary to supplement the feed with 200 mg of vitamin C / kg of feed, while the fingerling stage needs 100 mg vitamin C / kg of feed. Aquatic animals in the reproductive stage need a large amount of vitamins A, E, and C. Aquatic animals become more disease resistant when increased levels of vitamin C, E, B6, pantothenic acid and choline are added to the feed.

Vitamin requirements:

Each vitamin has its own structure and function. According to the dissolving properties, vitamins can be divided into two main groups as water-soluble vitamins (including vitamin B and C vitamin groups, choline and inositol) and fat-soluble vitamins (including vitamin A, D, E and K).

Water soluble vitamins

Studies have shown that water-soluble vitamins have a pronounced nutritional value although the function of some vitamins are not yet clear. For example, the main function of p-aminobenzoic acid, lipoic acid, and citrin is coenzymes in the cellular metabolism process. Some warm water fish species have the ability to synthesize some of these vitamins.

Thiamine (Vitamin B1)

Vitamin B1 is known as thiamine or thiamine chlohydrate. This co-enzyme is necessary for the metabolism of carbohydrates. Thiamine is therefore essential for fish growth and spawning. The thiamine requirement of fish is dependent on the amount of energy contained in the food. For example, the requirement for vitamin B1 increases with an increase in dietary carbohydrates for carps. Feeds with high energy content need to incorporate additional vitamins. It is suggested that omnivorous fish have a higher vitamin B1 requirement than carnivorous fish. The vitamin B1 requirement in fish is low and ranges from 1- 15 mg / kg, whereas it is 60 mg / kg in marine shrimp.

Studies have shown that animals fed dietary vitamin B1 deficiency usually display pathological symptoms after 8-10 weeks. The most obvious sign is a significant reduce in growth rate.

Thiamine mononitrate is the most common form of vitamin B1 in the feed. This is also the most stable form with a thiamine content of 88-91%.

Both processing and storage of vitamin B1 are very important as if it is stored at room temperature for 3 months, it will loss between 80-90% of its potency. In addition, it is unstable during processing. For example, pressing the pellet cause vitamin B1 loss between 0-10%, while it potentially losses 11-12% of its effectiveness if feeds are storage above 7 months.

Riboflavin (Vitamin B2)

Vitamin B2 (riboflavin) consists of flavin adenine dinucleotide (FAD) or flavin mononucleotide (FMN) which is an essential co-enzyme for ion exchange and many redox reactions.

Vitamin B2 requirement of carp and catfish is about 8-10mg / kg feed, and 25 mg / kg feed for shrimp. Signs of vitamin B2 deficiency includes reducing growth rates, anaemia, photophobia, skin and fins hemorrhage. These symptoms appear after 3 weeks for carps and after 8 weeks for catfish. Pale, unusual signs on the skin and easily stimulate are common signs of vitamin B2 deficiency in shrimps.

Vitamin B2 is easily lost through processing and feeding. When feed is extruded or put under pressure to create the feed it can lost up to 26% of its effectiveness and up to 40% potency when feed in the water.

Pyridoxine (Vitamin B6)

Vitamin B6 has the chemical name pyridoxine. B6 vitamins include pyridoxine, pyridoxal, pyridoxamine and several derivatives where the biological activity of pyridoxal is high. Pyridoxine is a coenzyme for the decarboxylation of amino acids, and therefore is involved in protein metabolism. Therefore, vitamin B6 plays an important role for fish and shrimp.

Vitamin B6 requirement of fish is about 5-10 mg / kg of feed, while in shrimp it is suggested to be 50-60 mg / kg. Signs of a vitamin B6 deficiency is elevated when foods are high in protein. Pathological symptoms of a vitamin B6 deficiency for carp appear after 4-6 weeks and for catfish after 6-8 weeks. The common signs are neurological disorders, reduced immunity, and anaemia, while for shrimp symptoms include a reduced growth rate and high mortality.

As a supplement to pyridoxine hydrochloride feed, vitamin B6 can be lost (7-10%) through both storage and processes such as pelleting.

Pantothenic acid (Vitamin B5)

Pantothenic acid participates in the formation of the acetyl coenzyme A which is an intermediate step in the metabolism of carbohydrates, lipids and proteins which play an important role in the physiological functions of growing fish.

The pantothenic acid requirement of fish is about 30-50 mg / kg feed. For shrimp, the recommended level is between 70 and 75 mg / kg feed. When pantothenic acid is deficient in the food for a long period the common manifestations seen in fish long are scrubrous gills, anorexia, necrosis, reduced growth rate. While in shrimp survival and growth rates are decreased.

Pantothenic acid is added to feed either as calcium d-pantothenate (92% active) or calcium d-pantothenate (46% active). The pelleting process can account for approximately 10% loss of the original pantothenic acid content.

Vitamin PP

Vitamin PP also called vitamin B3 or niacin. Most dietary niacin is in the form of nicotinic acid and nicotinamide both of which have the same effect and can be exchanged back and forth during metabolism. Niacin is a constituent of nicotinamide coenzyme adenine dinucleotide (NAD) and nicotinamide adenine dinucleotide phosphate (NADP). These coenzymes are involved in oxidation and reduction reactions during hydrogen transport and metabolism of carbohydrates, lipids, and amino acids. The requirement for vitamin PP is 14 mg / kg for carp, 28 mg / kg for channel catfish, 40 mg / kg of feed for shrimp.

Signs of vitamin PP deficiency in fish are skin and fin ulcers, skin haemorrhage, jawbone deformation and high mortality. Vitamin PP is found in plant foods and some animal tissues. However, the majority of vitamin PP in plants is difficult to absorb for fish. The vitamin PP content losses are about 20% as a result of the pelleting process.

Biotin

Biotin acts as a transporter of CO_2 in the carboxylation and carboxyl reduction chains. Biotin-containing enzymes that activate these reactions include acetyl-CoA carboxylase, pyruvate carboxylase and propionyl-coA carboxylase. Biotin participates in the biosynthesis of long-chain fatty acids and purines.

The Biotin requirement for fish is 1.5 - 2 mg / kg, while for shrimp it is 1 mg / kg feed. Catfish have the ability to synthesize biotin through their intestinal flora.

Biotin deficiency in fish is expressed as slow growth, pale skin, and in addition noise sensitivity when food is lacking biotin for long periods. The symptoms of biotin deficiency in shrimp are reduced survival and growth rates.

Biotin is common in animal food ingredients for example rice bran, wheat bran, meat meal, fish meal, corn meal, oil cakes are all a rich source of biotin. The most commonly used form of biotin in foods is d-biotin and about 15% of its potency is lost through the pelleting process.

Vitamin B12

Vitamin B12 is known as cyanocobalamin and neither animals nor plants are able to synthesize it however Vitamin B12 can be synthesized by the intestinal bacteria of some fish such as catfish Vitamin B12. Vital for embryo maturation and development, B12 is also known to play an important role in nucleotide, protein, carbohydrate, and fat metabolism in shrimp.

Research on vitamin B12 requirements for shrimp and fish is very limited, however, the recommended requirement of vitamin B12 for salmon is 0.015 –0.2 mg / kg, and for shrimp is 0.2mg / kg of feed. Reduced growth rates are the only indication of a potential deficiency in vitamin B12 and the manufacturing process is not thought to affect vitamin B12 content.

Choline and inositol

Choline and inositol belong to the water-soluble vitamin group but differ in that they are not components of coenzymes. Choline functions as i) a component of phosphatidylcholine that is involved in biofilm structure and lipid utilization in the body, ii) a component of the neurotransmitter acetylcholine and iii) a precursor of betaine. Betaine acts as a as an indirect methyl donor for methylation reactions such as the formation of methionine from cystine.

For crustaceans and fish choline and inositol are needed to preserve their structural integrity and thus have the basic function of participating in body structure and are therefore considered the most important water-soluble vitamin. The choline requirement for fish is very high 1,500 – 2,000 mg / kg (carp), 600 mg / kg feed for shrimp. Inositol requirement for fish is 500-1000 mg / kg and 400 mg / kg feed for shrimp. Signs of choline and inositol deficiency in fish are a decreased growth rate, liver swelling, intestinal and kidney bleeding. For crustaceans, growth and survival rate will be reduced.

Choline is added to feed in the form of choline chloride (70% choline) and is not lost through processing however when it is in water, it will lose about 10% potency after 60 minutes.

Vitamin C

Vitamin C has been identified as an essential vitamin for shrimp and fish. Vitamin C plays an important role in metabolism which involves in the growth and development of organisms by creating collagen. Enhancing shrimp and fish immune responses and disease resistance vitamin C also participates in the synthesis of corticosteroids. In addition, foods with a high vitamin C content are suggested to be beneficial for reducing shock in fish.

Food deficiency of vitamin C is the cause of pathological symptoms such as scoliosis in fish and black body mortality in shrimp. The larvae stage needs more vitamin C than adult stages, as it increases not only the growth rate but also the larval resistance. The required vitamin C content for fingerlings ranges from 25-50 mg / kg feed, while the level for shrimp is 100 mg / kg of feed.

To reduce the rapid dissolution of vitamin C in water, ethyl cellulose is used to encapsulate vitamin C particles (shelled AA formations). An alternative type of AA coating is to cover the oil with vitamin C or to use film-containing substances containing vitamin C. This layer of grease will prevent water seepage and oxidation during processing and storage. Vegetable oils are often applied as covers for vitamins. Once encapsulated vitamin C can result in maintaining a high content of 80 - 90% of active vitamin C and can be stored for several months without oxidation. The most successful method of increasing the durability of vitamin C is the incorporation of phosphate groups such as ascorbate-2-mono phosphate (AMP), ascorbate-2-poly phosphate (APP) or palmitic (ascorbyl-6-palmitate, AP). The presence of these groups will reduce the water solubility and oxidation of vitamin C.

Vitamins soluble in fat

The fat-soluble vitamins are vitamins A, D, E, and K. This group is absorbed through the intestine along with the fat in foods. Therefore, when the fat in the food is well absorbed, it facilitates the absorption of this vitamin group. Aquatic animals can accumulate fat soluble vitamins in the body when they are provided in excess of demand. Therefore, the demand for this vitamin group is very variable and depends on the amount of vitamins accumulated by the aquatic animal.

Vitamin A

Vitamin A has two forms: vitamin A1 (retinol) found in mammals and marine animals, vitamin A2 (3-dehydroretinol also known as retinol 2) found in freshwater fish. Vitamin A is needed for vision (the eyes), transporting Ca through the cell membrane, maturation, and embryo development. Juveniles are usually very sensitive to the lack of vitamin A in the diet, while at the adult stage, vitamin A can be accumulated in the liver so it is less affected. Some fish can convert b-carotene into vitamin A. Vitamin A is present in high levels in the eyes of shrimp. Certain types of carotenoids, such as astaxanthin, are also a source of vitamin A for both shrimp and fish. Vitamin A is found in fish oil. Therefore, when marine shrimp feed is supplemented with marine fish oil and carotenoids, the addition of vitamin A is not necessary.

Vitamin A has been shown to be necessary for the development of the ovaries, sperm chambers and embryos of crustaceans based on the accumulation of vitamin A in shrimp eggs during maturation. The recommended vitamin A content for fish feed is 1000-2000 UI / kg, while in shrimp, it is about 5000 UI / kg feed.

Signs of vitamin A deficiency in fish are anaemia, haemorrhaging in the eyes, gills, kidneys, and body colour changes. The type of vitamin A used to supplement foods is acetace, palmitate, and propionate. The vitamin A content can be lost through extrusion processes (~20%), and after 6 months of room storage (53%).

Vitamin D

Vitamin D is in two forms, Vitamin D2 (engocalciferol) and vitamin D3 (cholecalciferol). Vitamin D3 is more active and more often applied than vitamin D2 and is found mainly in animal sources. The most common form of vitamin D added to feed is vitamin D3 (cholecalciferol). Vitamin D plays an important role in the transport and absorption of both Ca and P.

The vitamin D requirement for warm water fish is between 500 and1000 UI / kg while 2000 UI / kg feed is recommended for shrimp. When foods are supplemented with large amounts of fish oil, it is often not necessary to add vitamin D. A deficiency or excess in vitamin D, can affect aquatic animals. Signs of vitamin D deficiency in fish and shrimp are reduced growth rates and a low mineral content in the body.

Vitamin E

Vitamin E, known in chemical terms as tocopherol, has several different forms, of which the alpha - tocopherol form contains the highest active concentration of vitamin E. One of the biological functions of vitamin E is to prevent the oxidation of polyunsaturated fats (HUFA) of lipids in biological cell membrane. Vitamin E plays a role in the synthesis and activity of sexual hormones.

The demand for vitamin E increases with high levels of PUFA in feed. Vitamin E requirement of fish is about 30-100 mg / kg and in shrimp is 100 mg / kg feed.

Signs of vitamin E deficiency in fish are slow growth, high mortality rate, and the accumulation of fat in the liver. The reproductive capacity and hatching rate of marine shrimp decreases when feed is provided with HUFA but lack of vitamin E. The recommended level of vitamin E supplement for marine shrimp in the maturation period is 600mg / kg feed. The maturation coefficient is also improved for carp when the feed is fully fortified with vitamin E.

Vitamin E biodegrades relatively easily through processing and storage, especially in tropical countries as the vitamin decomposes under high temperatures and humidity conditions and high trace mineral content. Therefore, the most used form of vitamin E in shrimp and fish feed is alpha - tocopherol acetate.

Vitamin K

Vitamin K plays an important role in blood clotting in animals and fish. A deficiency of vitamin K leads to the inability of fish to synthesize proconvertin and prothrombin in the liver, which are essential for blood clotting.

The requirement for vitamin K in fish is 10 mg / kg of feed, and in shrimp 5 mg / kg is recommended. In some shrimp species, when vitamin K is deficient, the growth rate decreases. Vitamin K is added to foods in the form of menadione salt, menadione sodium bisulfite (50% vitamin K3), a mixture of menadione sodium bisulfite (33% K3), and menadione dimethylpyrimidinal (45.5% K3).

Minerals

There are 6 macronutrients (Ca, Mg, P, Na and Cl) and 16 micronutrients (As, Cr, Co, Cu, I, F, Fe, Mn, Mo, Ni, Se, S, Si, Sn, Zn and V) that aquatic animals need. The microbiological functional groups of Cr, Co, Cu, Fe, Mn, Mo, Se, Zn, F all have important roles however the roles of Ni, V, Si and As have not been determined. However, studies show that aquatic animals need Ni, V, and As if cultured in water without minerals. Studies on the effects of a deficiency in P, Ca, Mg, Fe, Zn, Cu, Mn and Se have been studied on several shrimp and fish species. There are many obstacles when studying mineral requirements for aquatic animals because of the ability of aquatic animals can absorb minerals directly from the water environment.

Mineral requirements for aquatic animals depend on 1) Ingredients and effective mineral content in feed, 2) Mineral concentration in the aquatic environment and 3) The previous nutritional status of aquatic animals

Minerals have several functions including: 1) contributing to body composition, for example the macronutrients Ca, P, and Mg are important structural elements, 2) Maintaining normal physiological functions, 3) Acting as a catalyst for biochemical reactions, 4) Maintaining and acid - base balance for physiological functioning, 5) Contributing to the stabilisation of the body's osmotic concentration as well as maintaining the water balance, 6) Acting as neurotransmitters and hormone components such as iodine in Thyroxine that help the body adapt to internal and external conditions, 7) Key elements in the structure of blood such as Fe (haemoglobin), Cu (hemocyanin) and 8) Mineral exchange where the concentration of inorganic salts in the body and the external environment often varies greatly, so the body and the environment always have the process of exchanging mineral salts through the skin, gills, and intestines etc.

Macro-minerals:

Calcium (Ca) and Phosphorus (P)

Ca and P are essential for bone formation and the composition of fish bones often include a high percentage of Ca. In addition, Ca accounts for 19-21% of tilapia scales. The level of Ca in some fish species decreases during spawning and/or where there is a deficiency in the feed suggesting that Ca is absorbed from scales for physiological activities.

The ratio of Ca/P in scales and fishbone ranges from 1.5-2.1 while the ratio of Ca/P in the whole body is 0.7-1.6. In addition to the basic structure of bones, Ca is also actively involved in the process of hemodynamic, muscle contraction, transmission of nerve information, and maintenance of osmotic pressure. Meanwhile, P plays a role in the metabolism of nutrients in the body. P is a constituent of the high-energy compound Adenosine triphosphate (ATP), DNA, Phospholipid, RNA, and some coenzymes. Therefore, P is involved in the energy exchange process, controls reproduction, and growth. Phosphorus is also involved in maintaining pH stability in the body of aquatic animals.

Marine fish absorb large amounts of minerals from seawater, such as Ca, Na, Cl, and Mg, but very little P. The Ca content absorbed in marine fish is about 40 - 52% of that supplied from food. In contrast, freshwater fish absorb very little Ca from their diet.

P is mostly absorbed from food, with the rate absorbed from the surrounding water only 1/40 compared to Ca. The amount of P absorbed from the aquatic environment depends on the species, environmental factors, feed and Ca content in the water.

Signs of P deficiency include a decreased growth rate and a reduction in the efficiency of the species to absorb and use food and minerals. In addition, the common carp has shown signs of increasing fat content, reducing the amount of water in the body and the amount of P in the blood.

Types of Ca and P utilised:

The ability to absorb Ca of fish depends on the form and content of Ca, the composition of food and the structure of the digestive system of aquatic animals. In carp, when the Ca content in feed is 0.68%, fish can absorb 58% (calcium lactate), 37% (tribasic calcium phosphate) and 27% (calcium carbonate). Ca uptake capacity will decrease by 20 - 34% when P content is increased in feed.

Like Ca, P efficiency and absorption depends on the type of P used, the Ca content and the fish species. Monobasic phosphate Na and monobasic phosphate K are the most effective forms utilised by carp, tilapia, catfish and salmon. The ability to use calcium phosphate mixtures is highly variable with the monobasic form of calcium phosphate being the most effective.

The recommended Ca/P ratio for lobster is 0.56 / 1.1, for Japanese shrimp 1:1, while the black tiger shrimp is 1:1 to 1:1.5. The maximum Ca level suggested for shrimp is 2.3% in the feed, with a P level of 1-2%. For fish the recommended level of P is 0.29 - 0.8 but this is dependent on the species and type of P used.

Magnesium (Mg)

Mg has been determined to be a necessary mineral for shrimp and fish. The main function of Mg is the important in phosphorylation reactions and in some enzyme systems. In the liver, Mg is involved in increasing metabolic activity. The content of Mg in seawater is quite high, 1,350 mg / L. Both crustaceans and marine fish can absorb and eliminate excess Mg in the body. The level of Mg in the blood of marine fish is often lower than in the environment and therefore may not be necessary to add Mg in the feed. However, in low salinity or freshwater environment, it is necessary to supply Mg.

Pathological sign of Mg deficiency in catfish is decrease of growth rate. Additional symptoms of Mg deficiency are appetite loss, lethargy, high mortality and low Mg concentration in the body. The demand for Mg in fish depends on the content of Mg in the water, where the Mg content in water is about 1.35 - 3.5 g / L, the requirement level will be about 0.04 g / kg of feed.

Other macronutrients

Na, Cl and K are essential for the physiological activities of aquatic animals. However, there are many sources of these minerals present in both freshwater and seawater, especially in seawater. The main functions are the maintenance of osmotic pressure, acid–base balance, neurotransmission, and maintenance of the cell membrane structure.

The levels of K in freshwater sometimes is not sufficient for fish and an additional 0.3 - 0.8% K is required depending on the environment.

Micro-minerals:

Some elements are present in a very small amount (ppm) but have a marked effect on the body's metabolic processes. These micro-nutrients are known as the trace elements, such as Fe, Cu, and Zn.

Iron (Fe)

Fe in the body exists in the form of organic compounds such as haemoglobin or stored as inorganic Fe. In the diet, inorganic Fe is more easily absorbed than organic Fe. Fe plays an important role in respiration, therefore a deficiency of Fe results in a reduced red blood cell count and a yellow pigmented liver. Aquatic animals can absorb Fe in the environment, therefore the recommended Fe supplement for fish feed is about 60 - 150 ppm.

Copper (Cu)

Cu is a component of both the black pigment (Melanin) and of many enzymes that have an oxidizing effect. In addition, it plays an important role in respiration, stimulates the use of Fe and is a catalyst for the formation of Haemoglobin (Hb). For crustacean, the signs of Cu deficiency are reduced growth rates and a low level of Cu in the blood. Copper deficient fish also affects growth and fish are more susceptible to infection. The recommended Cu content for shrimp is 16 - 32 mg / kg feed. Cu content in fishmeal is quite high and is a good source of Cu for aquatic animals.

Zinc (Zn)

Zinc is a constituent of the enzyme carbonic anhydrase (catalysing hydration reaction) which increases the transport capacity of CO_2. In addition, carbonic anhydrase also stimulates secretion of HCl in the stomach. Zinc deficiency can result in a reduced growth rate and reproduction. The zinc requirement for fish ranges from 15 to 25 mg / kg and 15-20mg / kg for shrimp.

6.1.2 Ingredients for Feed

Feed ingredients are either sourced from the by-products of food processing for humans or are produced directly from raw materials. Feed ingredients for aquafeed are selected base on several reasons such as the nutrition value, digestibility, availability, physical properties, palatability, anti-nutritional factors, and cost. Each of these factors importantly influence on the production and physical quality of the final feed pellets.

Animal protein sources

Protein sources are feed ingredients having a protein content above 20% based on dry weight. Fish meal is the best protein source for aquafeed as fish meal provides balance profile of essential amino acids that meets the requirements of most aquatic animal species. In addition, fish meal has high digestibility. Several protein sources are derived from terrestrial animals have been used in the aquafeed such as meat, bones, poultry by-products and blood meal. Despite, these products have a high protein content, it may negatively effect on growth performance and feed utilization when high levels of these ingredients are included in the feed formula due to imbalance amino acids.

Fishery by-products

Fish meal is the best protein source of feed ingredient for aquafeed. Fishmeal is producing from clean, dried, ground tissue of undecomposed whole fish and/or fish cuttings. Fish meal has a high protein level, ranging from 45 to 70% and contains balance essential amino acids for aquatic animals and are high in polyunsaturated fatty acids (HUFA).

Shrimp head meal is produced from shrimp processing and is commonly used as an ingredient for shrimp diets. The crude protein content is around 35-40%. Shrimp head meal is a source of chitin, minerals, cholesterol, and astaxanthin. Shrimp head meal should not contribute more than 15% of the shrimp's diet and a maximum of 10% for fish feed.

Concentrated fish protein, containing a minimum of 70% protein, is prepared from clean, undecomposed whole fish or fish cuttings using a solvent extraction process developed to produce edible whole fish protein concentrate.

Animal by-products

Animal by-products are complementary protein sources in aquafeed. The protein content ranges from 50-80% and can replace 20 - 40% of fish meal in the formula for aquafeed. The apparent digestibility of animal by-products is high, and therefore have been used at significant levels in the commercial diets of several aquatic animal species. As a result, meat and bone meal, blood meal, poultry meal and feather meal are all considered as potential alternatives to fishmeal. However, these types of ingredients provide a limited source of essential amino acids and are also open to bacterial contamination.

Meat and bone meal is the rendered product from mammal tissues, including bone, and has a high protein content ranging from 50-60% with the protein content dependent on the quality of the processed ingredients. In general, the amino acid methionine, important for growth, health, and welfare of farmed fish species, is lacking in this meal so it is not widely used for aquatic animals. Meat and bone meals contain a minimum of 4% phosphorus with the calcium level 2.2 times that of the total phosphorus content.

Blood meal has a high protein content, (>80%) and is produced from clean, fresh animal blood attained from slaughterhouse processes. While blood meal is rich in lysine (9 - 11%), it is limiting in the amino acids isoleucine and methionine. As blood meals have a low level of digestibility the recommended amount is not more than 10% in feed formula.

Poultry by-product powder consists of necks, feet, feathers, and intestines and is sourced from poultry slaughterhouses. The protein content ranges from 58 – 60% but the protein digestibility is lower than 70%. The level of calcium must not exceed the total level of phosphorus by more than 2.2 times.

Similarly, hydrolysed feather meal is the product of poultry slaughterhouses. The protein content ranges from 80 - 85% and lacks both methionine and lysine. The digestibility of this meal is very low (about 50%) due to keratin being the main protein present.

Plant protein sources

There are several plant proteins used in aquafeed as these protein products which have a high nutritional value, with the protein ranging from 16-30%. In addition, the ingredients have high digestibility and balance essential amino acid profile. They also are economical and available. However, the protein level of these ingredients is very dependent on the species of plant and fibre levels are normally high. There are anti-nutritional factors in plant protein products which must be limited in aquafeed. Therefore, hydrothermal treatments such as extrusion, fractionation with water or polar solvents is required to reduce the content of these anti-nutritional properties.

Soybean meal is plant ingredient which commonly used in aquafeed as a protein source. Soybean meal is by product after removal of oil from dehulled soybeans by a solvent extraction process. Soybean meal has high protein level and good essential amino acid profile. Soybean meal is used widely in commercial aquafeed feed in the world.

Cottonseed meal is the product after removal of most of the oil from cottonseed by a solvent extraction process. It contains more than 36 % crude protein. Cottonseed meal is an important source of protein in aquafeed.

Pea meal has potential as an alternative protein source in aquafeed. The protein content ranges from 22 – 30%. Pea meal has poor essential amino acid profile and anti-nutritional factors. It can be used to replace fishmeal at a level of 10 - 30% in fish diet.

Canola meal is obtained from prepress solvent extracted from the whole seeds. It contains approximately 40% crude protein and maximum of 12% crude fibre.

Rapeseed meal is obtained by grinding the cake which after removal of the oil by mechanical extraction from rapeseed. Rapeseed meal contains a minimum of 32% protein

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Anti-nutritional factors

The anti-nutritional factors (ANFs) are components in plant feed ingredient that have a limiting effect on the feed intake, digestibility and nutrient absorption which inactivation of some nutrients, interference with the digestive process or metabolic utilization of feed and physiological responses. ANFs are generally not lethal in animals but may cause toxicity when consume in a large quantity of ANFs containing higher in diet.

Protease inhibitors are substances that can inhibitor the protease enzyme in digestive tract. Protease inhibitors depress growth and can cause hypertrophy and hyperplasia of the pancreas. They occur widely in many plants. Protease inhibitors are heat labile and will be destroy by heat.

Lectins are protein that occur depending on the development stage and on the part of the plant. Lectins reduce absorption of nutrients in the digestive tract and may cause coagulate the erythrocytes, the immune system or disrupt nutrient absorption in the intestines and reduce growth. Lectin activity can be removed by heat.

Phytates is common in plant seeds and major pool of phosphates in plants. Phytate significantly reduces the availability of minerals such as zinc, calcium, and magnesium including reducing the availability of dietary protein.

Tannin is phenolic compounds and common in many plants and tannin is complex heat stable. Tannin reduce the protein and carbohydrates digestibility. Another important property is their bitter taste, which reduces palatability leading to poorer feed conversion efficiency.

Energy Sources

Carbohydrates (Starch) improve the physical quality of aquafeed and are an inexpensive source of energy. Increasing carbohydrates, in the form of spare lipid or protein, in the formula is an efficient way to reduce the quantity of feed converted by oxidation to nitrogenous waste (ammonia) that is released into the environment. While, the majority of carbohydrates in aquafeed is sourced from plants, starch constitutes the major carbohydrate component of grains in feed. The digestibility of the carbohydrates within grains is highly variable with herbivorous species being the most efficient followed by omnivorous and carnivorous species, respectively.

Fats and oils provide energy sources for aquatic animals and are usually used in aquafeed as source of an essential fatty acid (omega-6 and omega-3). Fish oil is an excellent source of long chain n-3 PUFA (EPA and DHA) and is the main source of lipid in aquafeed formula. In general, vegetable oils such as soybean, rapeseed, canola, etc. can be used aquafeed without having any effect on the growth performance, feed utilization and health of the aquatic animals.

6.2 Feeding

6.2.1 Diet formulation

The formula for aquafeed is designed to suit the needs of each group of aquatic animals, and ensure adequate nutrition is provided. Therefore, diet formulation, requires an understanding of the nutritional needs of aquatic animals, and the nutrition provided by each of the feed ingredients. The diet must be balanced, and the nutritional components required by the body must be met. During all aspects of production and feeding food safety and hygiene must be ensured with the aim of increasing the preservation time and efficiency of using feed. Ideally the diets are low cost and yet highly effective, allowing the famers to gain a profit.

Nutritional requirement

The nutritional requirements of aquatic animals vary according to species, developmental stage, health, temperature, and other environmental conditions. In addition, the natural feeding behaviour of cultured species should also be considered. In order to develop a diet that meets the needs of aquatic animals, it is necessary to understand the nutritional value of the raw material selection.

Selection of ingredients

Energy sources: When high energy foods are needed, it is mainly cereal grain that is selected. Attention should be paid to the The formula for aquafeed is designed to suit the needs of each group of aquatic animals, and ensure adequate nutrition is provided. Therefore, diet formulation requires an understanding of the nutritional requirement of aquatic animals, and the nutrition provided by each of the feed ingredients. The diet must be balanced and met nutritional requirement of aquatic animals. Food safety and hygiene must be ensured during feed processing to increase the preservation time and efficiency of using feed. The diet cost is also considered when feed formulated.

Nutritional requirement

The nutritional requirements of aquatic animals vary according to species, developmental stage, health, temperature,

and other environmental conditions. In addition, the natural feeding behaviour of cultured species should also be considered. To develop a diet that meets the needs of aquatic animals, it is necessary to understand the nutritional value of the raw material selection.

Selection of ingredients

Energy sources: When formulated feed with high content of energy, cereal meal will be great candidate to select. Attention should be paid to the fibre content of the ingredients. If the fibre content is high, it will reduce both the palatability and the digestion of feed. In addition, fibre will also affect the stability of pellets. Raw materials with a high fibre content should not be used as feed for shrimp.

Protein sources: The best source of protein for aquatic animals is generally animal protein. However, to reduce the cost and ensure a balance of essential amino acids, the feed should be prepared from a variety of protein sources. Other animal or plant protein sources can be used to replace fishmeal, but the level of replacement should not exceed 50% of the total protein content. It is possible to supplement the aquafeed with synthetic amino acids, essential fatty acids, mineral premix, and vitamins where necessary.

Toxin: an important point to note when using plant ingredients is that they can contain toxins or antimicrobials. Therefore, it is necessary to process these ingredients before using to minimize the influence of these substances on the growth, health, and quality of fish.

Transformed biochemical composition: The quality of raw materials will vary depending on the region, season, processing, and storage techniques. Therefore, it is recommended to re-analyse the biochemical components of raw materials before formulating food. In addition, the nutrients in food can interact amongst themselves and there are four main types of interaction to be aware of:

1) Micronutrients with other nutrients: Feed lacking in vitamin B1 and having high carbohydrate content, results in fish having a lower resilience to disease, and increased mortality when compared to fish feed that also lacks vitamin B1 the diet consists of a high lipid content.

2) Minerals with minerals: The Mg levels within the feed depends on the Ca and P content.

3) Vitamins with minerals: Minerals absorption of the fish is limited when feed is deficient in vitamin D. In addition, vitamin C deficiency affects the absorption of Fe.

4) Vitamins with vitamins: Physical signs of disease will result in a more rapid onset of disease with a higher mortality rate if the food supply lacks both sources of B12 and folic acid.

Price and availability of raw materials

The price and availability of raw materials play an important role in the processing of aquatic feed.

6.2.2 Feed types in aquaculture

There are several types of aquatic feed applied in fish farm including larvae feed (e.g. fry, crustacean larvae), rearing feed, grow-out feed, conditioning feed for broodstock etc. The forms of feed include either moist or dry pellet feed: floating feed for fish, sinking feed for crustacean.

Moist feeds:

Moist feeds are commonly called home-made feed which have higher the moisture content (> 40%) and they are widely used in aquaculture. The main ingredients of moist feed include trash fish, seafood by-products, processing plants, and agricultural by-products such as broken bran, yam, etc, with vitamin, mineral premix. The composition of the moist feed and the ratio of ingredients vary depending on the capacity of the farmer, the availability of ingredients and the cost of the product.

The advantages of moist feed are the availability, palatability, and the lower cost, so this feed is not only used within extensive culture models but also feed for intensive models. The disadvantages of moist feed are the low feed efficiency due to the rapid dissolve in the water results in pollution the culture environment. In addition, the storage of moist feed is shorter, and it is high potential of transmission of pathogens and diseases.

Pellet feed (dry pellet feed):

Pellet feed has a low moisture content (<11%) and a high nutritional content compared to moist feed. The pellet feed has variety of sizes according to the size of fish's mouth. The optimal size of the pellets is approximately 20 – 30% of the size of the fish's mouth.

The advantages of pellet feed: easy storage and transport, less dependent on season, less risks of pathogen infection, suitable for automatic feeding machines and high stability. However, pellet feed costs are the higher and lack of palatability. In addition, the quality of the feed varies widely depending on the manufacturer.

6.2.3 Feeding management

Feeding Rate and Frequency

Feeding rate and frequency of feeding are vitally important for aquaculture practices. Underfeeding can result in reduction in productivity while overfeeding will cause a wastage of expensive feed and result in contaminating in culture water environment. Thus, feeding rate and feeding regime are needed to consider in farm practice to maximise profit.

Feeding rates and frequencies should not remain fixed in whole culture period. It must be adjusted according to the size and age of the fish or shrimp and water condition. Early stage of fish such as larval and fry requires a high-protein diet and excess feeding. Small fish need to be fed almost hourly due to having a high energy demand and feeding is nearly continuously. Larval and fry fish need to be offered a small amount of feed relative to the volume of culturing water. There are no negative consequences when small fish are fed excessively and with high frequency. However, feeding rates, frequencies, and dietary protein content should be reduced when fish are bigger. Instead of changing to a lower protein diet, farmers can choose to use the same feed, but reducing the quantity of feed is necessary during the grow-out period.

The amount of feed given daily to fish is calculated based on a percentage of total weight of the fish. For example, if there are 25,000 fish with the average body weight of 10.5 g and the recommended feeding rate is 7% per day, the amount of feed to be given daily is: (25,000 x 10.5 x 7)/100 = 18,375 (g) = 18.375 (kg).

Feeding frequency is dependent on several factors such as labour availability, farm capacity, the culture system, fish species and fish sizes. For example, large catfish normally fed only once per day due to time and labour limitations, while twice feeding per day is recommended for smaller fish. Fish may be fed up to five times per day to maximize growth at optimum temperatures in the indoor intensive culture system. The feeding rate is typically ranged 1 - 5% of body weight per day. However, it depends on several factors such as life stage, season, water parameters (temperature, dissolved oxygen). For example, it is not recommended to feed fish in the pond early in the morning when the dissolved oxygen levels are low. Feeding frequencies for different sizes and species of salmonids such as the coho salmon, chinook salmon and rainbow trout are suggested in Table 26.

Table 26 Suggested feeding frequencies for salmonids adapted from Piper et al. (1982)

	Fish Size (g)								
	0.3	0.45	0.61	0.91	1.82	3.6	6.1	15.1	>45.1
	No. of Feeding Times Per Day								
Coho salmon	9	8	7	6	5	3	3		
Chinook salmon	8	8	8	6	5	4	3		
Rainbow trout	8	8	6	6	5	4	4	3	2

Fish can be fed at nearly any time of the day when in a recirculating aquaculture system where the dissolved oxygen remains at a satisfactory level at all time. It is also important to adjust or reduce the feeding rate and frequency during the winter. The growers can determine amount of feed given base on feeding activity of fish. Feed conversion ratios and feed efficiencies can be enhanced when amount of feeding is managed properly.

Feed conversion ratio

The feed conversion ratio (FCR) is the amount of feed consumed to gain a kilogram. A low FCR means that only a small amount of feed is required to produce one kilogram of fish. Therefore, a low FCR indicates good feeding practice. Poor feed conversion ratio is often a result of poor feed management due to a lack of knowledge on aquaculture nutrition, inadequate distribution of feed and inferior feeding techniques. It is equation to calculate the FCR.

$$\text{FCR} = \frac{\text{Feed}}{\text{Animal Weight Gain}}$$

For example, if 1,400 kg of fish were cultured in a pond to which 2,200 kg of formulated diet had been used to feed during the growing cycle

$$\text{FRC} = \frac{2{,}200}{1{,}400} = 1.57$$

FCR of between 1.5 and 2.0 is considered a good feed conversion for most species.

6.2.3 Stability of feed

The stability of feed in water is different among feed types. Shrimp feed requires more stability to allow them to feed slowly compared to fish feed. The feed stability depends on the ingredients, the manufacturing process, and the binder.

Ingredients that are difficult to grind or have low adhesive properties should be used sparingly (e.g. bran, bone meal). Dehumidifying ingredients like sugar, salt, molasses make the food more likely to crumble. In general, substances that have a high adhesion when used in food production will make the food more stable in water.

6.2.4 Storage of feed

There are number of factors that can affect the feed quality during storage:

Temperature, humidity, and light

Temperature, humidity, and light influence significantly on the feed quality. These factors affect the moisture content of feed, the chemical decomposition the feed, fungi growing, moulds and insects. In addition, light is also responsible for the deterioration of food quality.

Microorganisms

In general, mould will easily grow at a humidity of above 70%, with a temperature range of 35 - 40^{o}C. The negative effects of fungal in feed is to reduce nutrient content, palatability and change the shape of feed. These microorganisms produce toxins that can cause cancer, especially *Aspergillus flavus*. Peanuts, cottonseed, and coconut are often contaminated with *A. flavus*.

Impact of insects and rodents.

Insects and rodents cause significantly which can damage the feed through biting, or indirectly by facilitating the growth of bacteria.

Chemical change during storage

Most of the chemical changes that often occur in feed storage are the rancidity of fatty acids. Usually unsaturated fatty acids are easily oxidized to create a rancid odour that reduces the quality of feed, sometimes creating some toxic compounds that inhibit the growth of fish. Carbohydrates can also be fermented. The chemicals produced in this process reduce the content of amino acids, valuable vitamins, especially vitamin C

Storage method

Storing feed properly can minimise the negative effects of temperature, humidity, bacteria, insect, and rodents. Feed ingredients should be stored for an appropriate time. Trash fish should be used immediately or stored in the freezer until use.

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7 Fish Health Management

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Intensive commercial aquaculture has been continually expanding to supply fish for human consumption worldwide. However, disease is now one of the main serious constraints leading to economic loss. Outbreak of disease is caused by three main factors including host, pathogens, and the environment (Figure 47).

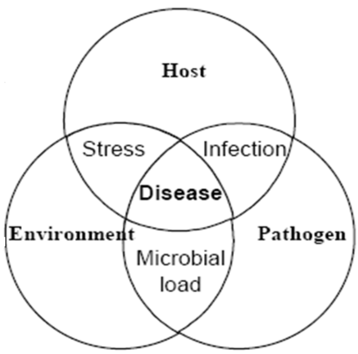

Figure 47 Factors relating to disease including host, pathogens, and environment.

7.1 Causes of fish diseases

Condition of the host: The strength of a fish depends on its age, species, strain, and physical condition. Although a fish has both innate and adaptive immunity to cope with pathogens, its immune responses often diminish in the migrating and spawning seasons. Genetically improved fish and certified specific pathogen-free fingerlings must be used in aquaculture to reduce the risk of diseases.

Environment: Fish are usually healthy in suitable environments; however, over-crowding leads to disease susceptibility and is quite likely in commercial ponds and cage cultures. Environmental problems include conditions of low dissolved oxygen, pH fluctuation, high ammonia, and high nitrite. Good water quality management and handling are necessary to prevent the spread of diseases. The prompt disinfection of fish injuries with suitable disinfectants at a recommended dosage is encouraged to prevent pathogen infection. The application of high quality feed ingredients which are free from contaminants, proper nutrient balance in feed formulation, prevention of loss of micronutrients during the feeding process, better handling, storage and feed management also have the best potential to improve the health of aquatic animals. Optimizing site selection can minimize disease outbreaks. The farm must be located in an area with an abundant water supply which is without toxic contaminants. Farm sanitation is particularly important in preventing the spread of disease. Fish handling and transportation lead to fish stress and this makes them prone to diseases. Season and environmental conditions contribute to disease risk. The greater the deterioration of the environment, the greater the severity of disease that occurs. Low water temperature results in delayed wound healing. In addition, fluctuations in temperature and pH are important risk factors that will result in infection by white spot syndrome virus (WSSV). Stressful conditions associated with poor water quality also lead to a decrease in feed intake, immune response and an increase in susceptibility to pathogens.

Pathogens: Major pathogens of cultivated fish include parasites, bacteria, fungi, and viruses. Potential sources of pathogens include:

- sick fish, dead fish or infected fish;
- infected eggs;
- unscreened broodstock and seed for infectious pathogens;
- water source;
- contaminated feed and living feed;
- contaminated equipment.

A disease outbreak involving concurrent infections of multiple pathogens resulting in death in cultured fish farms far outweighs any one single infection. Cultured Nile tilapia farms have recorded disease outbreaks which included up to five bacterial species in addition to a single virus. Disease is not caused only by pathogens, but other factors must be taken into consideration in order to manage fish health.

7.2 Types of fish diseases

There are two major forms of fish diseases including infectious diseases and non-infectious diseases.

7.2.1 Infectious diseases

Infectious diseases are caused by living pathogens (viruses, bacteria, fungi or parasites) present in the aquatic environment or carried by other fish. Fish are prone to pathogenic infections when there are stressors present (a fluctuating environment, water quality deterioration, nutrition deficiency, or body injuries) which weaken a fish's innate immunity. These are mostly contagious, or communicable, diseases. The following are the main kinds of infectious diseases:

Parasitic diseases

Fish parasites infest the gills, skin, muscle, and gut causing irritation, impaired function, weight loss, and eventually fish death which are often serious in small fish. Examples of parasitic infections include Ichthyophthiriasis (White Spot Disease) (caused by a protozoan), Trichodiniasis (caused by a protozoan), Gyrodactylosis (a trematode parasite), Lernaeosis (parasitic copepod), and fish lice (parasitic crustacean) (see Figure 48 for some of the dominant parasites). Parasite infection is often accompanied, or followed, by secondary bacterial or fungal infections.

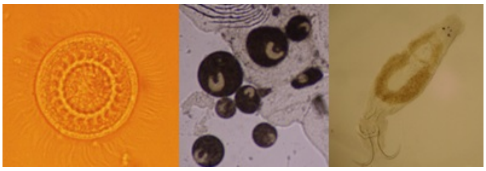

Figure 48 Some dominant parasites including *Trichodina* sp., *Ichthyophthirius* sp., and *Dactylogyrus* sp.

Bacterial diseases

Bacterial diseases may result from rough handling or the effects of parasitic infection. Generally, fish infected with a bacterial disease will have haemorrhagic spots or ulcers along the body. They may also have an enlarged, fluid-filled abdomen, and protruding eyes. The common bacterial infections of fish are: Vibriosis (Vibrio spp), Columnaris (Flavobacterium columnare), Furunculosis (Aeromonas salmonicida), Piscine tuberculosis (Mycobacterium marinum) and Streptococcal diseases (Streptococcus spp.) (Figure 49).

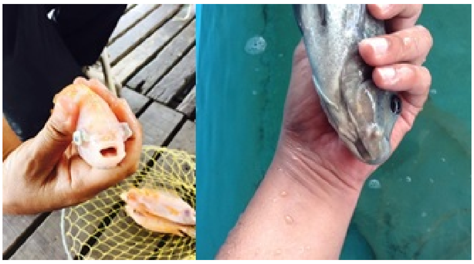

Figure 49 Clinical signs of tilapia infected with *Streptococcus* spp.

Viral diseases:

There are no specific medications available for viral diseases, therefore only prophylactic measures can be taken. The six major cyprinid viral diseases are: koi herpes virus disease (KHVD), spring viraemia of carp (SVC), grass carp haemorrhagic disease (GCHD), koi sleepy disease (KSD), carp pox disease (CPD) and herpes viral haematopoieticnecrosis (HPHN). The other important viral diseases affecting commercial fish production are caused by channel catfish virus and tilapia lake virus (Figure 50) while the ones affecting Asian shrimp aquaculture are white spot syndrome virus (WSSV) which causes white spot disease (WSD), yellow head virus (YHV) that causes yellow head disease (YHD), and covert mortality noda virus (CMNV) that causes covert mortality disease (CMD).

Figure 50 Discolouration of skin along with erosions and loss of scales in a moribund tilapia infected with tilapia lake virus (from Behera et al., 2018)

Fungal diseases:

Although fungal spores are common in the aquatic environment, they do not usually cause disease in healthy fish. However, when fish are infected with ectoparasites, bacteria, or injured by handling, the fungi can colonize the damaged tissues. These areas appear to have a cottony growth or may appear as brown matted areas when the fish are removed from the water (Figure 51). As fungi are usually a secondary problem it is necessary to diagnose the original problem in order to make effective prevention.

Figure 51 Tilapia infected with fungi

7.2.2 Non-infectious diseases

Non-infectious diseases can be caused by a genetic problem, nutritional disorders, or from a poor environment. Environmental diseases are the most important in commercial aquaculture. Environmental diseases include conditions of low dissolved oxygen, high ammonia, and high nitrite in the aquatic environment. Proper techniques of managing water quality will enable producers to prevent most environmental diseases. Gas bubble disease (GBD) occurs whenever the pressure of a gas (usually nitrogen and oxygen) in the water is higher than the pressure of that gas in the surrounding atmosphere. The super-saturation of oxygen in water due to a heavy algal bloom can lead to GBD in fish. Brown blood disease is also a typical environmental disease. This disease occurs when water contains a high nitrite concentration. Haemoglobin in red blood cells combines with nitrite to form methaemoglobin, which is incapable of oxygen transport, and the blood turns a chocolate- brown colour.

Nutritional diseases can be very difficult to diagnose. A classic example of a nutritional disease of catfish is "broken back disease," caused by vitamin C deficiency. The lack of dietary vitamin C contributes to improper bone development, resulting in deformation of the spinal column. Another important nutritional disease of catfish is "no blood disease" which may be related to a folic acid deficiency. Affected fish become anaemic and may die. The condition seems to disappear when the deficient feed is discarded, and a new feed provided.

Genetic abnormalities largely include conformational oddities such as a lack of a tail or the presence of an extra tail. Most of these are of minimal significance; however, it is important to bring in unrelated fish for use as brood stock every few years to minimize the effect of inbreeding.

7.3 Disease management strategies

7.3.1 Preventive strategies

The prevention of fish disease is better than treatment. For success in an aquaculture business, it is necessary to implement good practices in fish health management such as the following:

1) **Good pond preparation** is important. Earthen ponds should be dried after harvesting fish have been harvested within approximately 15 days, mud should be removed along with excessive waste from the pond bottom. Lime should be applied to kill some pathogen carriers or intermediate hosts; however, its requirement depends on the soil pH. Physical barriers including nets and fences should be erected to prevent invasion by birds, snails, crabs, and other parasite carriers as well as predators. Where shrimp farms have been faced with massive disease outbreaks and deaths, farmers must clean the ponds effectively to get rid of pathogens as much as possible and also apply intensive chemicals for water treatment.
2) **Disinfect equipment** regularly to reduce the risk of diseases and their transmission.
3) **Water treatment** can be done by a variety of methods including filtration, UV, ozonation, and chemicals to remove excessive organic substances and to kill the pathogens.
4) It is important to **use certified disease-free stock and quality control of fish seed** should be conducted. The vaccination of fingerlings is effective in stimulating an immune response and to prevent infection and spread of disease.
5) **A stress test of shrimp PLs** should also be applied to improve the strength of the seed. The seed should be dipped in water with an appropriate concentration of formalin, or saline, before releasing to reduce the external parasite infection. Aquatic animals must be cultured at reasonable densities as determined by species, size, number, type of rearing unit and water quality/availability. Too high stocking density leads to increased crowding stress, immune suppression, and higher vulnerability to disease. In addition, high stocking density results in high fish wastes, excess uneaten feed, and a high risk of acute hypoxia. Anaesthetic should be used to handle and transport live fish (Figure 52).

Figure 52 Gentle handling of fish fingerlings

6) **Water quality** should be kept at the optimum and should be monitored regularly. Dissolved oxygen levels should be kept above 3 ppm, while the level of unionized ammonia in a pond should remain below 0.02 ppm. The pH of the water should measure between 7.5 and 8.5. As light and water temperature affect both biological and chemical processes in aquatic systems, the water temperature must be kept at an optimal level without any fluctuations. Care should be taken to avoid abrupt changes in water temperature during fish transportation, stocking, and handling. An acclimation tank is needed to select out weaker fingerlings before releasing into the ponds.

7) **Provide suitable feeds** and appropriate feeding rates. A feeding program coupled with appropriately sized, high quality feed will fulfil the nutritional requirements needed for the growth and health maintenance of the fish. The amount fed will be influenced by many factors including water temperature, species, body size, and age. Trash fish/molluscs can be a source of betanodaviruses for cultured fish however, they pose a serious risk of outbreaks of VNN (viral nervous necrosis) in cultured sevenband grouper (Epinephelus septemfasciatus). It is important not to overfeed fish because excessive and uneaten feed can pollute the water and be food sources for pathogens. Store feed in a dry area without humidity and away from sunlight. The feeding behaviour of fish has to be observed carefully because stressed, or sick, fish can have a reduced appetite.

Fish should be observed daily for any unusual behaviour, visible lesions, or other sign of disease. Changes in behaviour, feeding, and physical condition should be diagnosed, although fish normally reduce feeding during the cold season. Feeding helps prevent weight loss and helps to make fish more resistant to diseases.

7.3.2 Therapeutic strategies

Before applying chemicals and antibiotics, a fish diagnosis must be conducted to find the precise cause of the disease. The correct water quality should be simultaneously checked. Several methods should be used to control infection by pathogens:

Salt concentrations 1 g/l (0.1%) could be applied to fish during live transport to reduce stress. Clove oil (50 – 100 ppm) can be used as a natural anaesthetic when handling. Treating ponds with benzalkonium chloride can reduce bacteria and fungi in the water. This chemical can be used to treat Zoothamnium in marine shrimps. Povidone iodine is widely used as a chemical disinfectant in aquaculture, as it is able to decrease the occurrence of diseases and improve the survival of fish.

Formalin (25 - 30 ppm) is used as an indefinite bath treatment to control parasitic infections on external surfaces (skin, fins, gills) of fish. It has been approved by FDA as a parasiticide for use on fish. Formalin is effective against many ectoparasites including protozoans and monogenetic trematodes. Trichlorfon is an organophosphate insecticide used to control fish lice and anchor worms.

In the UK, four antibiotics including oxytetracycline, oxolinic acid, amoxicillin and co-trimoxazole (Trimethoprim/ sulfamethoxazole,TMP/SMX) are approved for fish bacterial treatment. These antibiotics are usually applied as in-feed medication. Potassium permanganate immersion has also been used for columnaris treatment. In addition, hydrogen peroxide treatment has been known to reduce egg mortality and to increase the percentage hatch of channel catfish eggs regardless of whether eggs were incubated in a gelatinous matrix, or without the matrix, in comparison with an untreated control.

Do not use banned chemicals and antibiotics due to a raised awareness of the antibiotic resistance problem in fish. Withdrawal periods of antimicrobials used in fish are 21 days. While several antibiotics have been authorized for use in aquaculture (for example doxycycline, enrofloxacin, florfenicol, norfloxacin, oxolinic acid, sulfadiazine, sulfamethazine, sulfamethoxazole, sulfamonomethoxine, and trimethoprim), only five (amoxicillin, oxolinic acid, oxytetracycline, sarafloxacin, and trimethoprim-sulfadiazine) were authorized for use in the United Kingdom and by the FAO. Information regarding the use of antibiotics in aquaculture should be reconfirmed and updated with the specific information for the country of use.

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8 Genetics and Selective Breeding

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Aquaculture is predicted to play a major role in meeting the demand for protein as a food source. Selective breeding plays an important role improving the profitability of the aquaculture business and the quality and quantity of food available. Selective breeding of salmon and tilapia have seen yields increase by 60-80%. It is thought that less than 10 per cent of aquaculture production currently derives from selectively bred stocks, lagging significantly behind terrestrial animal and plant farming.

Selective breeding has seen significant improvement in profitability in terrestrial animals such as chickens, where egg laying increased from 120 eggs to 320 eggs and the milk yield of dairy cows increased from *2,000* kg to *5,000* kg. The average weight of pigs increased per day from 450 grams to 800 grams as a consequence of selective breeding over a 20-year period.
Genetic and selective breeding is seen as a necessary development to enable sustainable aquaculture development.

Genetic improvement occurs when the genetic merit is improved through selection i.e. the offspring will have a more desirable trait than the parents. Genetic selection is considered a traditional method, using the basic knowledge of quantitative genetics, and applying it for effective breeding. Selective breeding starts with the breeding stock, a group of animals used for the purpose of designed mating. The pedigree and performance data of the individual fish within the stock is recorded. Selective breeding experiments in aquaculture started in 1920s to improve disease resistance in fish, but it was not until the 1970s that the first family-based breeding program was initiated for Atlantic salmon in Norway by AKVAFORSK.

8.1 Genetic theory

The basic knowledge of genetics originated from Gregor Mendel's experiments with garden peas. From his observation on the inheritance of traits, he concluded a long-term trial that the genetic characteristics of each organism are based on a control unit called gene, and the gene is always paired, one from father, and another one from a mother that are able to convey to the next generation. When the results of Mendel's experiments with plants become known around 1900, the theory of genetics was established. The depiction of genetic characteristics later became the basis of modern genetics, known as Mendel's Laws:

Mendels' first law: The Law of Equal Segregation. When creating a gamete, members of each pair of alleles separate; each gamete will receive an equal probability of containing either allele.

Mendels' second law: The Law of Independent Assortment; during gamete formation two or more pairs of alleles from each loci/trait segregate independently of one another.

The genetic material of all known living organisms is stored in DNA (deoxyribonucleic acid) which are located in every cell nucleus (Figure 53). The double helix stand of DNA is organized into pairs of structures called chromosomes, with one being inherited from each parent. A segment of a DNA molecule (a sequence of bases) that codes for a particular protein and determines the traits (phenotype) of the individual is called gene. A locus (plural loci) is a specific, fixed position on a chromosome where a particular gene or genetic marker is located. A genome is an organism's complete set of DNA. The genome will vary widely between species, for example the number of chromosomes in each diploid cell in aquaculture species are 28 in mussels, 118 in prawns, 48 in grass carp, 60 in rainbow trout, and 58 in the Atlantic salmon. The number of chromosomes is considered to be stable within a species, however in several fish species, the number of chromosomes has been found to vary. Along the DNA molecule lie individual genes, the basic units of heredity in a living organism. A gene contains both coding sequences that determine the actual function of the gene, and non-coding sequences that determine when the gene is actively expressed.

These genes fundamentally affect nearly all traits in an individual, including obvious physical characteristics such as colour, length and weight, as well as behavioral characteristics. Because there are many genes/ loci in a whole genome, some traits are controlled by single gene or poly genes. A number of traits characterize the phenotype or appearance of an individual. Some traits can be classified through observation and show a discontinuous variation, we call qualitative traits. While, some traits cannot be classified by eye, requiring the trait to be measured and show a continuous variation, we call these quantitative traits.

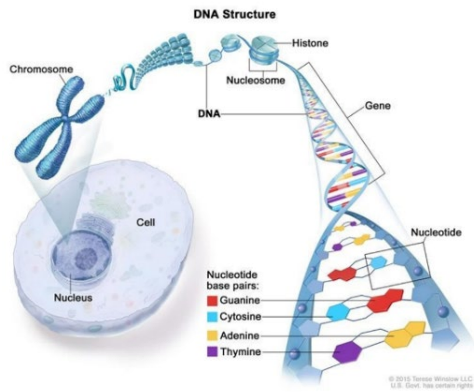

Figure 53 The relationship between DNA, genes and chromosomes.
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8.1.1 Qualitative/Single Gene Traits

Some traits are controlled by a single locus and show a simple Mendelian inheritance pattern, such as albinism in Thai walking catfish. In this case, the allele conferring albinism (white body and red eyes) is recessive, so must be present in two copies to be expressed (illustrated using trout in Figure 54). If, for examples, both parents of a Thai walking catfish family are heterozygous ‘Aa’ (Normal colour allele and albino allele), then the frequency of genotypes in their progeny will be 25% ‘AA’ (normal colour), 50% ‘Aa’ (normal colour) and 25% ‘aa’ (albino).

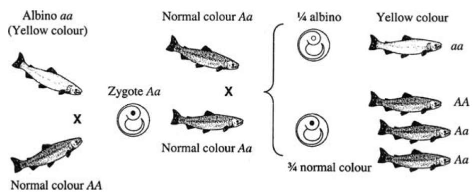

Figure 54 Inheritance of albinism in rainbow trout. Reproduced from Gjedrem and Andersen (2005) by permission of Springer.

The study of qualitative traits in mating and the principle of segregation, using the segregation ratio, allows for the identification of the allele which controls the trait observed in the F2 progeny. Genetic analysis often requires the interpretation of numbers in various phenotypic classes. The chi-square (χ^2) test can be used to quantify the various deviations expected by chance and thus can regulate genes such as complete dominant, incomplete dominant co dominant or additive genetic effect.

8.1.2 Quantitative / Poly Gene Traits

Traits of economic importance are quantitative traits and are usually controlled by several genes which may also be strongly influenced by environmental factors. A classic example of a quantitative trait of great interest to breeders is the body size or body weight. This is a complex trait that is influenced by a series of biochemical processes that are in turn are governed by many regulating genes. Different individuals may grow to the same size because of several different combinations of genes. In aquaculture, all traits of economic importance are quantitative, and the breeding theory of fish and shellfish is based on quantitative genetics.

The study of quantitative traits involves mating and the use of statistical methods to classify the variance component of phenotype and to identify which allele is influenced by genetics or environmental factors. Therefore, the phenotype (P) expression of quantitative traits is not only the genetic effects or genotype (G) but also environmental effects (E)

$P = G + E$

Allelic variation at individual loci, and the many possible combinations of alternative alleles, is what causes the genetic variation in any given trait. There are two broad categories of gene effects: Additive gene effects occur when the combined effects of alleles at different loci are equal to the sum of the individual effects. In many cases, however, the effect of a given allele depends on the effect of the other allele present at the same locus. This is known as the dominance effect and represents the interaction between alleles at the same locus. Interaction between alleles at different loci is known as epistasis. In general, dominance and epistasis effects are referred to as non-additive gene effects, implying that the effect of the alleles depends on interaction with other alleles. Only additive gene effects are fully transferred to the next generation in a strict and predictable way.

8.2 Selection using Heritability

In the selective breeding program, it is necessary to have basic information such as heritability (h^2) and the correlation of breeding values of traits. Therefore, it is necessary to study the genetic parameters before starting a breeding program, or it may be at risk of failure. However, it must always keep in mind that genetic parameters, such as age, condition, etc. change according to different environmental factors. Similarly, there are likely variances due to genetic differences in different aquatic populations. Using the same population as the previous year will result in an absence of gene flow which can lead to a reduction in genetic diversity and reproductive fitness.

Heritability is an important parameter in selective breeding. The genetic parameter is the relationship between the variation of the appearance (Phenotypic variance) and the variation of additive genetic variance. The heritability shows variable proportions that can be passed on to the next generation of animals by only additive genetic variance. The heritability is therefore used to predict genetic ability or the breeding value for the characteristics of each animal. In general heritability is a value that shows how difficult or easy it is to do selective breeding. It is important to note that heritability estimates are only relevant for the population studying and cannot be extrapolated to other populations. However, if the dataset is large and containing many full-sib and half-sib groups, the estimated heritability is more reliable and has a more general application.

Heritability is particularly useful for determining breeding methods. Heritability estimates range from zero to one. In aquatic animals, traits related to fertility, fitness, health, and survival are considered a low heritability if the value is less than 0.15, while values lower than 0.3 but higher than 0.15, are considered moderate. Heritability values higher than 0.3 are considered high. In addition, the heritability is also useful in assessing how a population will respond to selection.

Selection refers to choosing superior breeders to improve growth, product quality, disease resistance and other commercially important traits for the next generation. The effect of a particular allele on a trait depends on the allele's frequency in the population. While selection does not produce new gene/alleles, it changes the frequencies of alleles of genes with additive effects, resulting in an increase in frequency of favourable alleles and a decrease in frequency of alleles with a negative effect. In selecting the best breeders there are three known methods including Individual/mass selection, family selection and within family selection.

8.2.1 Individual / mass selection

Individual / mass selection is very popular. Here several individuals are chosen to mate based on appearance. Their progeny are further selected for preferred individual characteristics, without consideration of the average value by family and the process is continued for as many generations as is desired. Selection is convenient and several ponds and/or cages are not necessary. However, this method has disadvantages: there is no effective control for characteristics with low heritability and there is a have risk of inbreeding.

8.2.2 Family selection

Family selection or selection of a brooder is carried out through the selection or rejection of the whole family after taking under consideration the average family traits. In this selection program, there are many animals from many families reared separately. This method is labour intensive and requires extensive facilities to host the different families and therefore an important limitation, making this method unpopular. In addition, the efficacy of this selection depends on the number of aquatic animals per family, the family size. The greater the number of families hosted will result in the average family being more accurate, however, the efficiency of the selection will decrease with environment variation to which each family is exposed.

8.2.3 Within family selection

Within family selection is a selection of the best aquatic animals from each family. This method can reduce the number of ponds/cages required; however, the breeder will need to ensure there is a large component of environmental variance common to members of a family.

However, combined selection methods, that use mass selection in combination with family selection has the potential to achieve better results. Selection would be most efficient if one could measure the actual genotype of the animals, rather than the phenotype (which is the sum of genotype and environment). However, for the majority of traits it is only possible to measure the phenotype. For some traits with high heritability, measures of the phenotype will closely reflect the underlying genotype, while for traits with low heritability, phenotypic measurements reveal little about the genotype of the animal for that specific trait. Therefore, to compare the animals in selective breeding, the variance component of additive and non-additive genetic effects, should be analysed for variance and co-variance. Precision of variance estimation is importance by using a mating plan, pedigree, and the performance data of desirable traits. The precision of the variance estimation will provide an indication of how the phenotype of desirable traits is controlled by additive and non-additive genetic effects. One method currently used for many animal populations is the Restricted

Maximum Likelihood procedure (REML) which considers the genetic differences in the heterogeneity covariance between the genetic groups of animals. This procedure can show the variance of additive and non-additive genetic effects and environmental effects as a linear combination. It is also possible to estimate simultaneously the variance component of additive and non-additive genetic effects, environmental effects, and the covariance of the environmental effect of each animal that is used as a basis.

Advances in computer software has allowed for the determination of appropriate animal models to be used to carry out analysis of fixed and random effects for example in the evaluation of breeding in livestock a Mixed Model Equation (MME) was developed and is now applied to aquatic animals. The objective is to estimate the fixed effects and predict the random effects simultaneously by estimating the variance components are estimated by the restricted maximum likelihood (REML) method. Subsequently the Best Linear Unbiased Prediction (BLUP) will make use of the composition of the predicted variance of Estimated Breeding Value (EBV) for any desirable trait of each animal. BLUP is used in linear mixed models and are used to predict the random effects. BLUP is now a widespread approach applied in predicting the genetic abilities of animals. In aquatic animals, this method uses a nested design to create a population from different families, and then uses a model to study the genetic parameters where both univariate and multivariate analysis are sometimes used to study the interactions between genetics and environmental factors. For example, the genetic parameters of weight at harvesting and survival rate under the commercial farming conditions of the Pacific White Shrimp (*Litopeneaus vanamei*) has been studied.

In a selective breeding program, breeders need to consider differences in selection and selection intensity, which will determine the success of the next generation. Very intense artificial selection can erode genetic variation for example if the parents are too small this may cause what was originally a large population to decline and further selection for the next generation may cause inbreeding.

8.3 Best broodstock selection

After selection the breeder chooses one of two popular methods to get the best broodstock, namely comparison with unselected or control populations or random sampling.

8.3.1 Comparison with unselected/control populations

Comparison with unselected/control populations through randomly sampling all size categories from the base population and comparing to selected populations of the same condition. The resulting difference between the selected group's average and the control group's average is the response to selection. However, inbreeding is a serious concern with the control population in addition to the effects of random genetic drift and natural selection and therefore it is recommended to use this method for only a few generations.

8.3.2 Bidirectional selection

To reduce problems caused by the use of controlled populations, a population that has been selected as a low performer is used as a comparative population. The response to selection is equal to the difference in the average of the selected population plus the negative population or low performer. In fact, the response to this two-way selection is often unequal. Negative selection often responds better than positive selection.

Furthermore, genetic trend analysis can be studied from the estimated breeding value (EBV) by using the average breeding value each year or from each generation to create a graph to see the past selection trends that have changed for the positive or negative.

Furthermore, the data system for recording pedigree and performance of the desirable traits for each species within the any selective breeding process is very important. Breeders need to assess the ability of each animal in the population to make selection decisions according to the goal of the breeding program. The breeding plan must consider the population structure, i.e. relationships, and the ability of the species to express the traits to be improved. A key consideration for any offspring model is that the desirable trait is improved in the next generation. Improvements in any breeding programme is a circular process feeding into the selection, and/or breeding cycle of the next generation and evaluating the data collected during each cycle to improve the efficiency and accuracy of reproduction.

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Additional Information

Students focusing on selective breeding are encouraged to read more in the book 'Selection and breeding programs in aquaculture' (Gjedrem, 2005), which provides more detail on selective breeding plan/design, method for analyzing the data, how to select the brooders, and how to calculate the selection response.

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

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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 production1. 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 world3. 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. 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. 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. There-fore, they observe and monitor environmental trends closely so that they can adjust their practices when necessary.

Figure 55 Traditional sea cage

Aquaculture farmers in Vietnam are especially vulnerable to change. Sea cage farms are located off shore 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 first hand. 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 first hand 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.

9.1 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.

9.1.1 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.

Table 27 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 infrastruc-ture and escaped stock. Increased soil salinisation from infiltration.

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 off shore location leaves them unprotected from storms. A typhoon will destroy a sea cage farm's infrastructure. There-fore, 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 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.

Figure 56 Feeding cobia

Figure 57 Shrimp nursery

9.1.2 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.

9.1.3 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 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.

9.2 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.

9.2.1 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 arming 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.

Figure 58 Water quality monitoring test kits

Table 28 Summary of climate change 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.

9.2.2 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. 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.

Figure 59 Growing biofloc

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 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.

9.2.3 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 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.

Figure 60 Hatchery produced pompano seed

9.3 Conclusions & 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 industry's 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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