INITIATIVE ON Asian Mega-Deltas

THE INLAND AQUACULTURE INNOVATION TECHNOLOGY DEVELOPMENT IN CAMBODIA

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ABBREVIATION

AFTA	ASEAN Free Trade Area
ASEAN	Association of Southeast Asian Nations
CAST	Commercialization of Aquaculture for Sustainable Trade
CBF	Culture-Based Fisheries
CFR	Community Fish Refuge
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
FAO	Food and Agriculture Organization of the United Nation
FiA	Fishery Administration
GAPs	Good Aquaculture Practices
GaqP	Good Aquaculture Best Practices
GDP	Gross domestic product
IT	International Tender package
JICA	Japan International Cooperation Agency
MAFF	Ministry of Agriculture, Forestry and Fisheries
MEF	Ministry of Economic and Finance
MoU	Memorandum of Understanding
na	non-available
NACA	Network of Aquaculture Centres in Asia-Pacific
NADS	National Aquaculture Development Strategy
NGO	Non-Government Organization
PSMA	Port State Measures Agreement
RAS	Recirculating aquaculture system
ROI	Return on investment
RUA	Royal University of Agriculture
SIS	Small Indigenous Fish Species
SME	Small & Medium Enterprise
SPS	Sanitary and phytosanitary
UNCLOS	United Nations Convention on the Law of the Sea
UNFSA	United Nations Fish Stock Agreement
VA	Value added
VC	Value chain
WTO	World Trade Organization

I. General Background

1.1. History and general overview of Aquaculture in Cambodia

Cage and pen culture, reportedly originating in Cambodia, is the major farming system of freshwater aquaculture production and its history dates back to the 10th century. As a result of the particularities of the hydrological cycle of the Mekong River and its natural buffer reservoir, the Great Lake, the freshwater fish catch has always been highly seasonal, especially for the large carnivorous fish such as Channa sp. and Pangasius sp. which are choice edibles of the affluent segment of the population. Pond culture was first introduced in the 1960s through pond culture of Chinese carps and tilapia that was attempted around Phnom Penh, the capital city, and in some plantation and garden ponds.

Aquaculture in Cambodia had been reemphasized since 1984 after a long disruption starting in 1975. Owing to the abundance of wild fish in Cambodia, in the past aquaculture did not play an important role in the volume of fish supply. However, cage and pen fish culture was used in the Tonle Sap Great Lake region before 1950 on account of the readily available seed supply from the wild, especially of Pangasius catfish. Presently, cage and pen culture is becoming increasingly popular. Most of the farms are located in the Great Lake and Mekong/Bassac rivers (77%), while fewer are found in the other lakes (23%). Aquaculture development in Cambodia is now showing signs of more rapid growth, and is at a critical stage in its development. According to official government statistics, aquaculture production in Cambodia has grown from around 26,000 tonnes in 2005 to 120,055 tonnes in 2014.

On the other hand, the Community Fish Refuges (CFR) is a method that was established in 1994 whereby broodstock are protected for the following breeding season through the use of communal ponds, either natural, artificial or in rice-paddies, during the dry season. The number of CFRs is increasing annually, from 29 in 2005 to 802 in 2014. Through the CFRs the production of fish in the rice fields has also increased. However, within the culture based fisheries organized by Network of Aquaculture Centres in Asia-Pacific (NACA) since 2012, 16 Culture-Based Fisheries (CBFs) were installed throughout the country for the conservation of fish and freshwater prawn. Each zone hosts a fisheries administration officer that is responsible for the implementation of CBFs with the community. The CBF method is being used to encourage people to understand the communal value of public water bodies, and how they benefit their food consumption and small-income generating activities during harvest season.

Aquaculture production has grown significantly. In 2012 it stood at 74,000 tonnes, or almost 11 percent of total fishery production. By 2016 it had grown to 172,500 tonnes, almost 22 percent of total production (MAFF, 2018). Freshwater aquaculture systems include cages and pens, intensive ponds, extensive homeland ponds, community fish refuge (CFR) ponds and integrated rice-fish farms. A CFR is a form of stock enhancement or a fish conservation measure that is intended to improve the productivity of rice field fisheries by creating dry season refuges for brood fish in seasonally inundated rice fields (Olivier et al., 2012)

In coastal areas, aquaculture systems include fish and shrimp farms (Jörg, 2013). There are also 825 community fish refuge ponds. Cambodia still cannot export crocodile skins to international markets because its farms have not yet been able to fulfill industry standards. Currently, 16 farms have applied for a CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) license, while only six have so far obtained approval to export skins. Having obtained a CITES license, in 2015 Cambodia reached a landmark deal to export 1,000 crocodile skins to France, where buyers want grade C skins, a standard which is not so hard to meet (Can, 2015). Cambodia currently exports crocodile skins to the European Union. Also, it exports crocodile skins and meat to Vietnam, Thailand and China.

In 2014, a Japanese 'third water' technique was introduced in Cambodia whereby artificial river and sea water is created through blending fresh water with a mix of minerals, including salts of sodium, potassium and calcium. The project, in the mountainous province of Takeo, is led by the Japan International Cooperation Agency (JICA). Roughly 30,000 giant river prawns, which sell for eight times the price of fish in Cambodia, are to be reared at each of three farms.

1.2. Potential area for aquaculture development in southeast Asia

Due to the relatively high costs of consumables, farming fish is weakly profitable for some types of producers, such as cage producers (home-made feed being the major cost) or high input semi-intensive producers. The net profit margin and the return on investment (ROI) are particularly high for the low input semi-intensive producers, the intensive producers, the processors and the retailers. The net profit is high for the traders because of the volume of their sales. The value added and contribution to growth The total value added (VA) of the sector has been estimated at 399 million €, contributing 2.4% to the national gross domestic product (GDP), 9.2% to the agricultural GDP and 41.2% to the fisheries (Table 1).

Table 1: Indicates regional and country aquaculture production, contributing to the world

Country/area	Aquaculture production (2021)		Population (2021)		GDP per capita (2021)[3]	
	Tonne	Share of world total (%)	Million	Share of world total (%)	Current USD	Ratio to world average (%)
World	126,035,297	100.00	7,909	100.000	12,351	100.00
Least Developed Countries	4,566,511	3.62	1,100	13.902	1,179	9.55
Asia	115,269,861	91.46	4,695	59.355	8,105	65.62
South-eastern Asia	24,458,889	19.41	676	8.544	5,004	40.52
Countries in South-eastern Asia, ranked by aquaculture production in 2021						
1. Indonesia	14,606,534	11.5892	274	3.461	4,339	35.13
2. Viet Nam	4,749,274	3.7682	97	1.232	3,793	30.71
3. Philippines	2,272,528	1.8031	114	1.440	3,461	28.02
4. Thailand	989,898	0.7854	72	0.905	7,060	57.16
5. Myanmar	929,217	0.7373	54	0.680	1,211	9.81
6. Malaysia	416,978	0.3308	33.6	0.424	11,111	89.96
7. Cambodia	348,350	0.2764	17	0.210	1,603	12.98
8. Lao People's Democratic Republic	135,008	0.1071	7.0	0.094	2,496	20.21
9. Singapore	5,244	0.0042	5.9	0.075	71,334	577.54
10. Brunei Darussalam	4,768	0.0038	0.4	0.006	31,457	254.68
11. Timor-Leste	1,091	0.0009	1.3	0.017	2,740	22.19

Source (FAO, 2021 and UN 2022)

Natural resources of Cambodia contribute about 0.14 percent of world land area (including inland water surface area); 0.12 percent of world inland water surface area; 0.06 percent of world coastline length; 0.87 percent of world total renewable water resources (Table 2).

Table 2: Indicates total area of surface inland water bodies and total renewable water resource

Country/area	Total country area (excluding coastal waters; 2020)[1]		Surface area of inland waterbodies (2020)[2]		Coastline length (2019)[3]		Total renewable water resources (2020)[1]	
	km2	Share of world total (%)	km2	Share of world total (%)	km2	Share of world total (%)	Billion m^3/year	Share of world total (%)
World	133,780,390	100.00	3,494,970	100.00	805,942	100.00	54,737	100.00
Least Dev. Countries	20,801,236	15.55	272,183	7.79	32,413	4.02	7,258	13.26
Asia	31,965,369	23.89	772,188	22.09	186,507	23.14	14,442	26.38
South-eastern Asia	4,507,810	3.37	86,694	2.48	103,846	12.89	6,395	11.68
Countries in South-eastern Asia, ranked by aquaculture production in 2021								
1. Indonesia	1,916,862	1.43	39,195	1.12	54,716	6.79	2,019	3.69
2. Viet Nam	33,230	0.25	7,651	0.22	3,444	0.43	884	1.62
3. Philippines	300,000	0.22	8,524	0.24	36,289	4.50	479	0.88
4. Thailand	513,120	0.38	8,861	0.25	3,219	0.40	439	0.80
5. Myanmar	676,590	0.51	10,358	0.30	-	-	1,168	2.13
6. Malaysia	330,800	0.25	5,227	0.15	4,675	0.58	580	1.06
7. Cambodia	*181,040*	*0.14*	*4,337*	*0.12*	*443*	*0.06*	*476*	*0.87*
8. Lao PDR	236,800	0.18	2,275	0.07	0	-	334	0.61
9. Singapore	728	0.00	50	0.00	193	0.02	1	0.00
10.Brunei Darussalam	5,770	0.00	85	0.00	161	0.02	9	0.02
11. Timor-Leste	14,870	0.01	132	0.00	706	0.09	8	0.02

Data sources: 1. FAO AQUASTAT main country database (November 2020; downloaded on 29 April, 2023). 2. FAOSTAT Land Cover database (CCI_LC; updated on 15 July, 2022; downloaded on April 29, 2023).

1.3. Scope of the Report

This assignment is mainly based on literature review on the inland aquaculture in Cambodia. The report covers freshwater aquaculture, it comprised of the current state of Cambodia aquaculture, not going deeply on applied technologies by types and farming systems inside the cycle of aquaculture practices but overall development technologies, the challenges and future outlook, regardless socio-economic and climate change perspectives.

1.4. Legal frameworks

1.4.1. LAWS AND REGULATIONS RELATED TO FISHERIES TRADE

The following are the articles related to the transport and trade of fish and fishery products under Chapter 12 of the Fisheries Law of Cambodia in 2006:

Article 64. Commercial transportation of fishery products in the Kingdom of Cambodia shall need a license and be under the inspection of Fisheries Administration. Procedures of transporting fishery products as stipulated in paragraph 1 of this article of this law shall be determined by the proclamation of the Ministry of Agriculture, Forestry and Fisheries (MAFF).

Article 65. A physical or legal person who transports fishery products shall pay premium on fishery products to the Fisheries Administration (FiA), except for families use and research purposes. The rate of premium on fishery products shall be determined by the proclamation of the MAFF and the Ministry of Economy and Finance (MEF). The specification of fishery products shall be determined by the proclamation of the MAFF.

Article 66. Commercial export of fishery products can be taken place, when:

- A license has been issued by the head of the central FiA.
- A license has been issued by the CITES Management Authority of Cambodia for endangered fishery products although it is not for commercial purposes.
- A quality control certificate in fishery pathology has been issued depending on the demand of importing country.

Article 67. Commercial import of fishery products can be taken place, when:

- A license has been issued by the head of the central FiA.
- A license has been issued by the CITES Management Authority of exporting country for endangered fishery products although it is not for commercial purposes.
- A quality control certificate in fishery pathology has been issued by the exporting country.

Article 68. Exporting, importing, buying, selling, transporting, processing and stocking of endangered fishery products shall only be authorized for products from aquaculture and/or in compliance with article 64, 65, 66 and 67 of the law on fisheries and CITES Convention. The endangered fishery products shall be determined by a sub-decree.

Article 69. The following shall be prohibited:

- Buying, selling processing stocking and transporting of fishery products from illegal fishing or using illegal fishing gears.
- Commercial transportation of fishery products without license; or contradicting the license such as specification of fisheries products, quantity, validity, direction and/or by-pass, and transportation means.
- Transportation of illegal fishing gears in fishery management area.

Transportation of fishery products in the closed season that have no stocking license or have not deducted from stocked quantities.

1.4.2. INTERNATIONAL TRADE AGREEMENTS

Cambodia is a member and signatory of the following international trade agreements:

- Convention on Fishing and Conservation of Living Resources of the High Seas in 1960
- International Convention for the Regulation of Whaling since 2006
- United Nations Convention on the Law of the Sea (UNCLOS) in 1983 (signed but not yet ratified)
- Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 1997
- Association of Southeast Asian Nations (ASEAN) in 1999
- ASEAN Free Trade Area (AFTA) in 1999
- World Trade Organization (WTO) in 2004
- Memorandum of Understanding (MoU) related to fisheries with Viet Nam in 2011
- MoU related to fisheries with Thailand in 2019
- Port State Measures Agreement (PSMA) (under process)
- United Nations Fish Stock Agreement (UNFSA) (under process)

II. Current State of Aquaculture in Cambodia

2.1. Role and contribution to socio-economy

Capture Fisheries and Aquaculture in Cambodia plays an important role in food security and livelihoods throughout the country (Robert and Murari, 2018). Cambodia people are among the highest consumers of freshwater fish in the world, with annual per capita fish consumption estimated at 52.4 kg (FiA, 2019) whereas Needham & Funge, 2014 found Cambodia was highest in Southeast Asia, at 63.5 kg per capita per year. Moreover, more than 80% of the total animal protein in the Cambodian diet is estimated to come from fish and other kinds of aquatic animals, most of which come from inland water bodies (Nam & Bunthorng, 2014). Aquaculture is practiced in both freshwater and marine environment conditions and occurs at multiple scales, from small-scale, subsistence production to large-scale, commercial production. In Cambodia, more than half of total production is freshwater cage culture, which dominates the sector. Though, smallholder high-input pond aquaculture represents only about 18% of total production.

Aquaculture production in Cambodia increased from 14,430 tonne in 2000 to 348,350 tonnes in 2021. The 16.37 percent annual growth was higher than sub-regional, regional and world averages (xx). Aquaculture production in Cambodia increased from 6 thousand tonne in 1990 to 348 thousand tonne in 2021; the share of aquaculture in total fisheries production increased from 5.7 percent to 40.7 percent (In the past, the fish and fisheries products demand in Cambodia was largely met from freshwater capture fisheries. Though, in recent decades, growing demand for affordable fish from both rural areas and fast-developing urban centers has resulted in increased fishing pressure, which poses the main threat to the sustainability of Cambodia's capture fisheries. Aquaculture development is thus vital to both meet the growing demand for fish and manage the country's fisheries resources sustainably.

Aquaculture is mainly depending on numerous ecosystem service, including water provisioning and nutrient cycling and growing quite rapidly, and takes many different forms-from very extensive enhanced rice field fisheries to intensive pangasius, snakehead, and hybrid catfish culture. The government has set a 20% growth rate target for aquaculture, and there is an important potential for a wide range of sustainable aquaculture activities at different scales in marine and freshwater environments. The freshwater aquaculture accounts for approximately 90% of national aquaculture production (https://www .agrifarming.in/aquaculture-in-cambodia-a-full-guide #freshwater-aquaculture-in-cambodia).

2.2. Farming systems distribution and characteristics Freshwater Aquaculture

Cambodia contains many water resources, such as the Great Lake Tonle Sap, the Mekong River, the Tonle Sap River, the Bassac River and many of their tributaries. A number of these lakes are potential sites for aquaculture. The activity of freshwater aquaculture includes culture in cages, ponds and pens, where the most potential cage culture locates the open Tonle Sap Lake and along the Tonle Sap and Mekong Rivers. Most of the culture activities are located in areas which have abundant water resources or which are irrigated. Recently, fish culture areas have spread throughout the country, including the upland areas. Freshwater pond culture covers a total area of 1,350 ha of earthen ponds, comprised of 39,955 ponds. Floating net-cage culture is also important and covers 12 ha, comprised of 4,224 cages (FiA, 2014). These cages are used primarily for snake head (Channa striatus), giant snake head (Channa micropeltes), silver barb (Barbonymus gonionotus), Pangasius spp. and Mystus spp.

2.3. Classification of Aquaculture and number

Aquaculture in Cambodia is separated as freshwater and marine, and is subdivided as small-, medium- and large-scale but the aquaculture practices are predominately small-scale. Culture based fisheries is particularly important in the rural remote areas in the upland region of the country where exotic species have been introduced into water bodies. Fish are raised in Water Based Systems such as cage and pen, Land based systems such as pond, raceways, tanks and recirculation systems.

Small scale aquaculture referred to the operations typically involve less than 1-2 hectares of water surface area for aquaculture activities and often aimed at household consumption with surplus sold in local markets and income generation. Farmers often rely on locally available resources and traditional methods, and the use of low-cost, simple technologies is common and frequently integrated with other agricultural activities, such as rice farming or livestock raising, to enhance productivity and resource efficiency and may involve multiple species, including freshwater fish (tilapia, catfish, carp), shrimp, and aquatic plants, often selected based on local market demand and ecological suitability. Small scale aquaculture operations are based on traditional knowledge and practices, often passed down through generations, family-run, with labor provided primarily by family members. Many small-scale farmers practice polyculture, raising multiple species together to optimize resource use and enhance production

Medium Scale Aquaculture are typically involved an operational water surface area ranging from 2 to 10 hectares, produce a significant quantity of aquatic species, often targeting both local and regional markets, with production volumes that can be several tonne per year, higher initial investment compared to small-scale farms, including infrastructure, equipment, and technology, employ more advanced practices and technologies, such as aeration systems, water quality monitoring, and improved feeding strategies, to enhance productivity. Medium-scale aquaculture often cultivates a range of species, including popular freshwater fish (tilapia, catfish, and others), shrimp, and potentially some marine species, depending on the geographical location. These farms may practice both polyculture (raising multiple species together) and monoculture (focusing on a single species), based on market demand and management practices.

Large Scale Aquaculture referred to the operations usually encompass over 10 hectares of water surface area, often extending to hundreds of hectares depending on the species and farming techniques used, generate high volumes of aquatic products, often exceeding hundreds of tonne per year, aimed at both domestic consumption and international markets.

Following the inter-ministerial instruction number 327 សណន-កសក on Procedures and Conditions for the Provision of Administrative Services in Ministry of Agriculture, Forestry and Fisheries dated on 14 September 2021, the permission letter needed from any physical person or legal entity based on the total surface of their ponds, cage, pens and species raised as the following:

- For freshwater aquaculture
  - ✓ The total surface of pond from 10,000 m^2 to 20,000 m^2
  - ✓ The total surface of cage from 50 m^2 to 250 m^2
  - ✓ The total surface of pen from 5,000 m^2 to 10,000 m^2
- For species Raised (*channa striata* and *channa micropeltes*)
  - ✓ The total surface of pond from 1,000 m^2 to 2,000 m^2
  - ✓ The total surface of cage from 150 m^2 to 250 m^2
  - ✓ The total surface of pen from 500 m^2 to 1000 m^2
  - ✓ More than 10,000 heads to 35,000 heads

Following the sub degree number 182,183 and 184 អនក្រ.ប្រក on function and administration structure of municipality, Phnom Penh city and district dated on 2nd December 2019, the permission letter needed from any physical person or legal entity based on the total surface of their ponds, cage, pens and species raised.

- For freshwater aquaculture
  - ✓ The total surface of pond from 5,000 m^2 to 10,000 m^2
  - ✓ The total surface of cage from 15 m^2 to 50 m^2
  - ✓ The total surface of pen from 2,000 m^2 to 5,000 m^2
- For species Raised (*channa striata* and *channa micropeltes*)
  - ✓ The total surface of pond from 200 m^2 to 1,000 m^2
  - ✓ The total surface of cage from 15 m^2 to 150 m^2
  - ✓ The total surface of pen from 100 m^2 to 500 m^2
  - ✓ More than 5,000 heads to 10,000 heads

Cambodia contains many water resources, such as the Great Lake, the Mekong River, the Tonle Sap River, the Bassac River and many of their tributaries. A number of these lakes are potential sites for aquaculture. The activity of freshwater aquaculture includes culture in cages, ponds, pens and rice-fish. Most of the culture activities are located in areas which have abundant water resources or which are irrigated. Recently, fish culture areas have spread throughout the country, including the upland areas. Freshwater pond culture covers a total area of 1,350 ha of earthen ponds, comprised of 39,955 ponds. Floating net-cage culture is also important and covers 12 ha, comprised of 4,224 cages (FiA, 2014).

2.4. Aquaculture System in Cambodia (Extensive, semi-extensive and intensive)

Among the three levels of aquaculture, it was also divided into three culturing system, i). Extensive culture with no intentional nutritional inputs and stocked animals depending on natural food organisms in the pond or brought in through the water supply, ii). Semi-intensive culture with natural food organisms enhanced by pond fertilization providing all or most of the nutrition, in the latter case being complemented by supplementary feed 'Semi-intensive fish culture' is defined by fish receiving most of their nutrition from natural food sources that have been intentionally stimulated by fertilization and/or feeding artificial foods to supplement the natural food, and iii). Intensive culture with more or less all the nutrition for the cultured organisms being provided in added feed e.g., either traditionally in the form of trash fish for carnivorous fish or artificially formulated feed, usually in pelleted form.

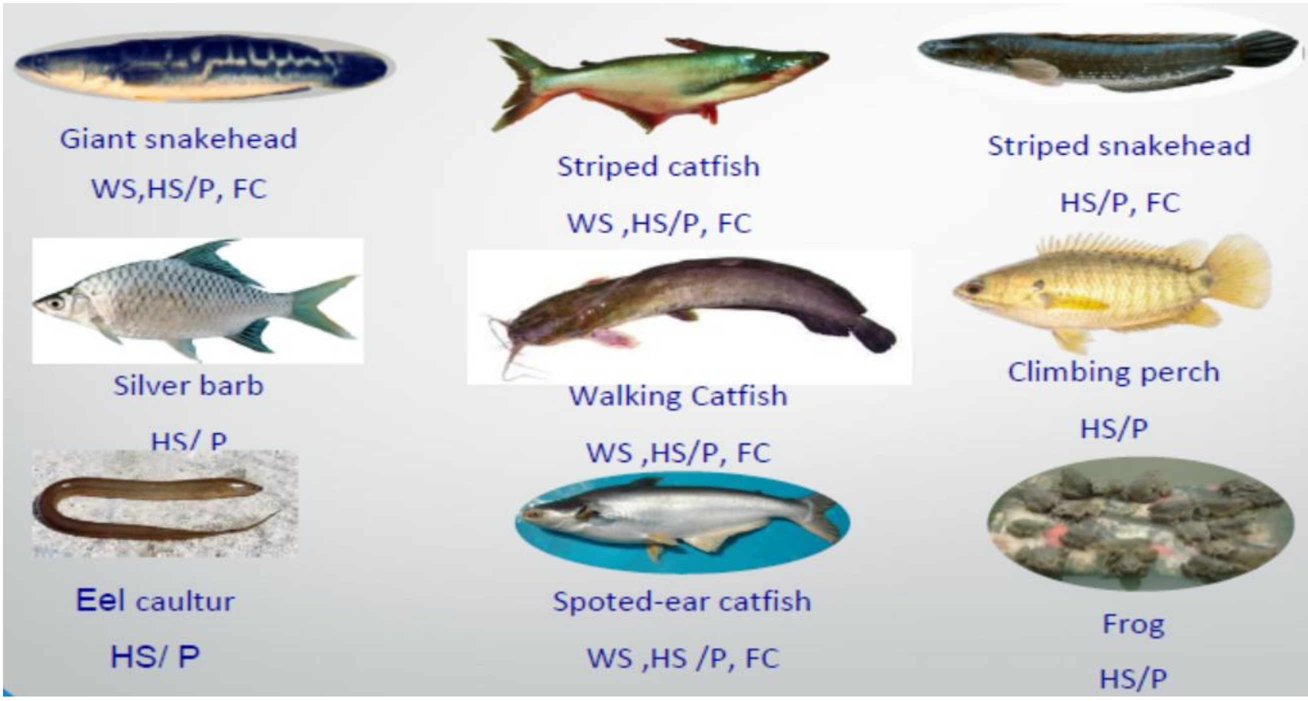

Photo: Indigenous inland farming species

2.4.1. Pond Culture

Ponds are constructed water bodies, usually with earthen sides (embankments, dikes, bunds) and bottom. Water exchange with the surrounding environment is usually limited so that a pond is essentially a static body of water. However, water may be allowed to enter the pond through various means of water delivery systems as well as rainfall, to fill it up with water and to maintain the level of water. It is usually necessary also to drain the pond for adequate management, including harvest of all the fish.

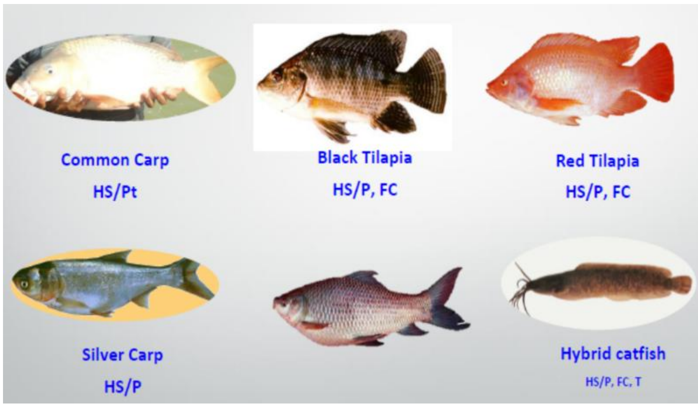

Photo: Exotic inland farming species

Pond culture was first introduced in the 1960s through pond culture of Chinese carps and tilapia that was attempted around Phnom Penh, the capital city, and in some plantation and garden ponds (FAO, 2024). There are various types of ponds based on their method of construction and the typography. Ponds constructed specifically for aquaculture

should be drainable to facilitate management although there are many types of undrainable ponds. There are three basic types of ponds: excavated, dike and watershed ponds.
Excavated ponds are basically a hole in the ground and often are constructed for other purposes e.g., borrow pits for soil. The water level is below ground level so drainage requires pumping. The excavated soil may surround the pond and serve for flood protection.

In the construction of dike ponds a shallower hole is constructed than for excavated ponds and the soil is used to build the dike, minimizing the amount of earth that needs to be moved. The water level is thus above ground level. These are typically built with machinery on flat land with soil compacted.

Watershed ponds are built on sloping land by excavated soil to form a dam across an elongated depression or a valley. The slighter the slope of the ground level, the greater the pond water surface area from building a dike of a given height. If the terrain is not flat, as both the slope and angle of the valley decrease, the suitability of the site increases for pond construction. Watershed ponds can be divided into two types:

- Barrage ponds which are built in narrow valleys in which the dam blocks the stream so the water overflows from pond to pond.
- Diversion ponds where the stream or river is not blocked but water is diverted into ponds. This becomes increasingly feasible in valleys with gentle slopes and angles. The ideal situation is where the topography allows ponds to be constructed with individual water inlets and outlets. Water gates would permit optimal control e.g. with stagnant water for extensive/semi-intensive culture in which it would be unwise to flush out the natural food in the water; and in flowing water for intensive culture to maintain water quality.

Small-scale pond culture has a more recent origin, during 1960s when Chinese carps and tilapia were first grown around Phnom Penh and in some plantation and garden ponds. Small-scale aquaculture usually implemented in wild fish-scarce areas, during the last decade (Tana, 2002). Traditionally small ponds provide water for household use, watering vegetables and livestock and as a source of wild fish. Increasingly small ponds are used to stock fish. There has been a surge in pond construction over the last one to two decades, both in floodplains and in upland areas, in response to the increasingly unreliable availability of water as well as more widespread development of aquaculture (Edwards et al., 1997).

Photo: Homestead pond aquaculture

2.4.2. CAGE AND PEN CULTURE

Cage and pen culture are reported to have originated in Cambodia, and is the major inland aquaculture production system. The method was first used in the 10th century (Limsong and Thuok, 1999, Nam and Thuok, 1999, Sour and Viseth, 2004). It seems to have originated as a way of growing on non-marketable size fish caught in fishing lots. However, cage and pen culture, reportedly originating in Cambodia, is the major farming system of freshwater aquaculture production and its history dates back to the 10th century (FAO, 2024). As a result of the particularities of the hydrological cycle of the Mekong River and its natural buffer reservoir, the Great Lake, the freshwater fish catch has always been highly seasonal, especially for the large carnivorous fish such as Channa sp. and Pangasius sp. which are choice edibles of the affluent segment of the population.

The fish first being stocked in pens for fattening during the dry season and then transferred into floating cages in the wet season. Bamboo and wooden cages used to hold wild fish caught in the Tonle Sap lake in Cambodia were later developed into cages to culture fish, possibly around a century ago. The higher water level at this time of year enables the cages to be floated downstream to markets (Tana, 2002).

A cage and pen as defined here is a culture facility that encloses a volume of water, which is exchanged with that of the water body in which it is placed via spaces in the sides and bottom of the structure. It differs from a pen, which is an enclosure of water in which the substrate of the water body is the bottom of the culture facility, because the supporting frame for the sides is driven into the substrate. There are various types of cage structures:

- Suspended cages with the enclosure supported by stakes driven into the substrate of the water body
- Floating cages supported in the water by floats
- Submerged cages, which often sit on the bottom of the water body
- Submersible cages, the depth of which can be adjusted in the water column.

Photo: Cage culture in Kampong Chhnang Province, Tonle Sap Lake

Traditional cages are constructed from pieces of wood or bamboo with spaces between them to allow for water exchange. The enclosure is therefore acting as both the frame and the 'net'. Floating cages supported with bundles of bamboo as floats operated in Cambodia with various designs and sizes. Cages may be square or rectangular "boxes". Living quarters for the guard or the family are often built on top of the cage. Many cages in Cambodia are constructed as boats with live holds for fish and are also used to transport fish to market.

Modern cages have an enclosure or bag made of usually flexible synthetic fibres in the form of a net. The most widely used material for the net is polyamide (nylon). The enclosure of floating cages is supported by a frame at the surface of the water made of wood, galvanized steel or high-density polyethylene pipe. Commonly used materials for floats to support the frame and bag include bamboo rods, fibreglass, metal or plastic drums, PVC pipes and Styrofoam blocks covered with polythene sheets. Synthetic materials are more expensive than bamboo but last for many years. Bamboo has a relatively short life span of 2–3 years. The net is attached by rope to the frame and is kept stretched with weights at the bottom of the cage. Cages in moving water are anchored. The floating frame at the surface may serve also as a working platform (0.5–3m wide). Alternatively, the cage can be serviced by boat. Cages should be provided with a net cover to prevent fish from jumping out or being preyed on by fish-eating birds.

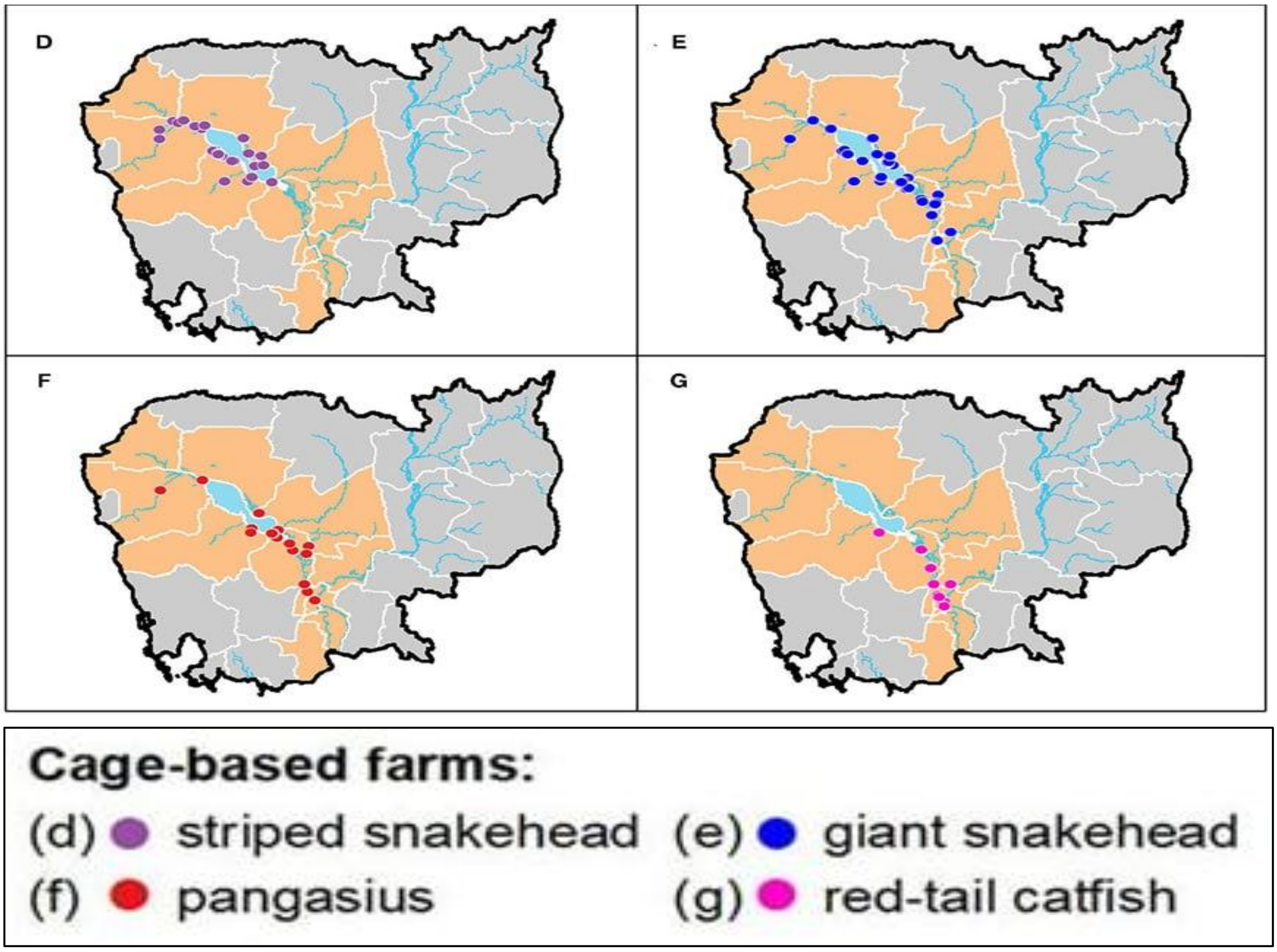

Figure 1: Indicates location of the cage culture and farmed species (Source: Joffre et al., 2021)

2.4.3. Rice Fish Culture

Rice-fish culture is an extensive form of aquaculture where fish are released into flooded rice paddies. This form of aquaculture reduces the reliance on feeding fish with collected feed such as termites, earth worms, duck weed and rice bran. Rice-fish culture was introduced into Cambodia, particularly in Prey Veng and Svay Rieng Province (Romeas Hek district) in 1994-95 and the number of rice-fish farms grew to 40 by 1995-96, but has decreased to only about 20 now due to drought conditions and has been also introduced in Takeo Province where there are 25 rice-fish farmers in 2005 (Viseth & Pengbun, 2005).

Several physical modifications have been devised over the years in order to make the rice field better suited for fish culture. All modifications have the basic goals of providing deeper areas for the fish to grow without inundating the rice plants and of limiting escape from and access to the rice field. This is achieved either by making portions of the rice field deeper than the ground level for the fish, or conversely, by creating areas higher than the ground level for the rice or other crops. There are four physical improvements that are commonly made to prepare rice fields for fish culture. The first is to increase the height of the dike or bund to allow deeper water inside the field and/or to minimize the risk of it being flooded. The second is the provision of weirs or screens to prevent the fish from escaping as well as keeping predatory fish from coming in with the irrigation water. The third, which is not always practiced but often recommended, is provision of proper drains and finally, provision of deeper areas as a refuge for the fish. Once the fish are inside the rice field, efforts are made to prevent them from escaping with the water, regardless of whether it is flowing in or out. To prevent loss of the fish stock, farmers install screens or weirs across the path of the water flow such as bamboo slats, a basket, and a piece of fish net material. Rice field embankments are typically low and narrow since the usual rice varieties do not require deep water. To make the rice field more suitable for fish, the height of the embankment needs in most cases to be increased. Reports on rice-fish culture from various countries show embankments with a height of 40–50 cm (measured from ground level to crown). Since the water level for rice does not normally exceed 20 cm, such embankments will already have a freeboard of 20-30 cm. This is sufficient to prevent most fish from jumping over. The height of the embankments cannot of course be increased without a corresponding increase in the width. There are no hard and fast rules as to the final width, but generally it is within the range of 40-50 cm. (FAO et al.,2001).

In Cambodia, there are four designs and constructions of fish trenches, 1– peripheral trench; 2 – peripheral with one central longitudinal trench; 3 – peripheral with two equidistant transverse trenches and 4- small pond or borrow pit inside rice field.

Photo: Integrated rice-fish farming system in Tramkak district, Takeo Province

2.4.4. Fish and Aquaponic Culture

Aquaponics is a bio-integrated system that links recirculating aquaculture with hydroponic vegetable, flower, and/or herb production. Aquaponics, also known as the integration of hydroponics with aquaculture, is gaining increased attention as a bio-integrated food production system. Aquaponics is essentially the combination of Aquaculture and Hydroponics.

Photo: Aquaponic system the Royal University of Agriculture, Chamka doung

Both aquaculture and hydroponics have some down sides, hydroponics requires expensive nutrients to feed the plants, and also requires periodic flushing of the systems which can lead to waste disposal issues. Re-circulating aquaculture needs to have excess nutrients removed from the system, normally this means that a percentage of the water is removed, generally on a daily basis. This nutrient rich water then needs to be disposed of and replaced with clean fresh water. "research has shown that an aquaponic system uses about 1/10th of the water used to grow vegetables in the ground" (Joel Malcolm et all, 2007).

However, Aquaponics is still not considered cost effective on the commercial scale in Cambodia, but most of the researches have been applied at research institutions and university, i.e. researchers at RUA are looking to change that situation by experimenting with inexpensive growing media and a variety of different crops, such as lettuce greens, Chinese broccoli and bitter melon. Currently, the aquaponic system has not been applied at local scale where some areas of the country facing with electricity supply as well as local community could not afford to the solar energy system.

2.4.5. Plastic Tank culture

Plastic tanks for fish culture have emerged as a practical solution in Cambodia's aquaculture sector, the system addressed several challenges such as space limitations, water quality management, and the need for sustainable practices. Here's a closer look at the benefits, and examples of plastic tank fish culture in Cambodia.

- Space Efficiency: Example: Urban fish farmers in cities like Phnom Penh can use plastic tanks in limited spaces such as backyards or rooftops. This allows for fish farming in areas where traditional pond farming isn't feasible.
- Plastic tanks facilitate better control over water quality, allowing farmers to monitor and adjust conditions more easily than in open ponds. For instance, farmers can more readily manage parameters like temperature and dissolved oxygen levels, leading to healthier fish.
- There's less risk of water pollution affecting local ecosystems. This is crucial in areas where fish farming might otherwise lead to runoff and contamination of freshwater sources.
- Fish cultured in plastic tanks can be isolated from wild fish populations, reducing the risk of disease outbreaks. For example, tank-raised tilapia can be monitored closely for health issues, allowing for quick interventions.
- Harvesting fish from tanks is often simpler and less labor-intensive than traditional methods. This efficiency can lead to reduced operational costs.
- Plastic tanks can be moved as needed, providing flexibility in farm management. For instance, farmers can relocate tanks to take advantage of seasonal weather
- While tanks save on water and space, the initial investment in plastic tanks may be higher than traditional pond systems, which can be a barrier for some small-scale farmers.
- Plastic tanks are typically suitable for small to medium-scale operations. Larger producers may find them less viable compared to traditional open pond systems.

There are some successful implementations such as Community Fish Farming Initiatives through Programs supported by NGOs, such as the WorldFish project, have introduced plastic tank systems in rural communities, promoting sustainable practices and providing training on fish farming techniques. Many families have successfully adopted tank-based systems for tilapia or catfish, improving food security and income.

Photo: Plastic tank in Battambang province

2.4.6. CONCRETE TANK CULTURE

Photo: Aquaculture product in Takeo province

Concrete tanks for fish culture in Cambodia present a robust alternative to traditional aquaculture methods, particularly in addressing issues related to water quality, disease management, and space utilization. Here's an overview of the benefits, and examples of using concrete tanks in Cambodian aquaculture.

- Built to last, resistant to wear and tear from environmental factors. They can withstand extreme weather, making them ideal for long-term fish farming operations.
- Enables better control of water parameters (temperature, pH, and dissolved oxygen). This stability supports healthier fish growth. For instance, farmers can more easily maintain optimal conditions for species like tilapia and catfish.
- Unlike open ponds, concrete tanks minimize the risk of fish predation from birds and other wildlife, protecting stock and reducing mortality rates.
- With a contained environment, farmers can monitor fish closely and implement biosecurity measures more effectively, reducing the spread of diseases.
- Constructed in various sizes and arranged vertically, maximizing the use of available land. This is especially beneficial in areas with limited space, such as urban settings.
- Can easily use recirculating aquaculture systems (RAS), where water is filtered and reused, conserving resources and reducing environmental impact.
- The cost of building concrete tanks can be substantial compared to other methods like plastic or earthen ponds. This upfront investment may deter small farmers from adopting this technology.
- Unlike plastic tanks, concrete tanks are permanent structures and cannot be moved, which may limit flexibility in farm management.
- Many larger commercial farms in Cambodia utilize concrete tanks for breeding and raising fish, such as tilapia and catfish. These operations often focus on meeting local and export market demands, leveraging the durability and efficiency of concrete systems.
- Some farms combine concrete tanks with other agricultural practices, such as growing vegetables or rice, utilizing nutrient-rich water from the tanks for irrigation. This integrated approach enhances sustainability and diversifies income sources.

There are some initiatives supported by organizations like FAO and WorldFish have promoted the construction of community-based concrete tanks to improve food security and promote sustainable aquaculture practices and some innovative farmers are integrating aquaponics with concrete tanks, allowing for the cultivation of fish alongside plants. This method maximizes resource use and creates a symbiotic environment that benefits both fish and crops.

III. CULTURED SPECIES AND AQUACULTURE VALUE CHAIN

Today there are another native species introduced for aquaculture. it was snake head, elephant ear gourami, snakeskin gourami, climbing perch, eel, shrimp, soft shell turtle, crocodile and frog and another exotic species were cray fish and apple snail. However, the cultured fishes include both indigenous and exotic species. The major cultured species are stripped catfish about 73% followed by giant snakehead accounted for 21%. Other species produced include Puntius sp., Philippine catfish (*Clarias batrachus*), marble goby (*Oxyeleotris marmorata*), *Cirrhinus sp*., red tailed tinfoil (*Barbonymus altus*) and Hoven's carp (*Leptobarbus hoeveni*). Hoven’s carp is often caught during times of abundance, and then stocked and fattened for a few months before being sold at a better price during lower fish catches. (FiA/FAO, 2014).

Table 3. Indicates the most common farming species in Cambodia and its contribution the world aquaculture production

Aquaculture species groups by production quantity		Cambodia (all areas; quantity; 2021)				
WAPI species group	ISSCAAP division	ASFIS species items in the group farmed by the country		The country's aquaculture production quantity of each species group (live weight; tonne)	Share of the country's aqua. production quantity of all species (%)	Share of world aqua. production quantity of the same species group (%)
		Total	Effective			
1. Catfishes (Siluriformes)	Freshwater fishes	2	1.3	110,880	31.83	1.81
2. Carps, barbels and other cyprinids (ISSCAAP group)	Freshwater fishes	7	2.9	106,360	30.53	0.34
3. Snakeheads (Channidae)	Freshwater fishes	1	1.0	75,660	21.72	10.99
4. Gouramies (Anabantoidei)	Freshwater fishes	2	1.4	24,610	7.06	10.03
5. Tilapias and other cichlids	Freshwater fishes	1	1.0	12,180	3.50	0.19
6. Clams, cockles, arkshells	Molluscs	1	1.0	8,000	2.30	0.14
7. Mussels (ISSCAAP group)	Molluscs	1	1.0	5,480	1.57	0.27
8. Marine shrimps and prawns (ISSCAAP group)	Crustaceans	1	1.0	1,390	0.40	0.02
9. Red seaweeds (ISSCAAP	Aquatic plants	1	1.0	1,000	0.29	0.01
10. Marine perch-like fishes	Marine fishes	2	2.0	960	0.28	0.06
Other species		*7*	*n.a.*	1,830	*0.53*	*n.a.*
Aquatic products		26	7.7	348,350	100	0.28

Source: FiA/FAO, 2014

3.1. Local consumption demand

The demand for baseline local fish consumption in 2020 was estimated 44.91kg/capita/year, whereas the total demand against to the total population was 736,386 tonne for capture fisheries while aquaculture contributes about 399,400 tonne. The estimation until 2030 was the same to baseline year while the total population will increase by 18 million (Table 4).

Table 4. Indicates fish consumption demand against to total population in 2030

Cambodia	Baseline (2020)	Projection to 2030	
		Year 2030	2030 compared to baseline
1. Per capita fish demand	44.91	44.91	-
2. Population (thousand)	16,397	18,084	1,687
3. Total fish demand (tonnes)	736	812,166	75,781
4. Fish supply from aquaculture	399	776,677	377,277
5. Supply-demand gap (tonnes)			**301,496**

Notes: Fish and seafood includes finfish, crustaceans, molluscs and miscellaneous aquatic animals. 1. Cambodia's per capita fish and seafood consumption in 2020 baseline is assumed to be the same as the level in 2019 (44.91 kg). 2. Population data from UN World Population Prospects (2022 revision). 3. Equal to (1) x (2). 4. According to FAO Fishery and Aquaculture Statistics – Global aquaculture production 1950-2021 (FishstatJ), Cambodia's farmed fish and seafood production increased from 205,300 tonnes in 2017 to 347,350 tonnes in 2021. Following the linear trend during 2017–2021, the country's farmed fish and seafood production would reach 776,677 tonnes in 2030, 377,277 tonnes higher than the 399,400 tonnes in 2020. 5. Equal to (4)–(3).

3.2. Aquaculture Value Chain in Cambodia

Value chain refers to the full range of activities that are required to bring a product (or a service) from conception, through the different phases of production, to delivery to final consumers and disposal after use (Kaplinsky,1999; Kaplinsky & Morris, 2001).

The value chain starts from the production system of the raw materials and will move along the linkages with other enterprises engaged in trading, assembling, processing, etc. It includes all its backward and forward linkages, until the level in which the raw material is produced will be linked to the final consumers and value chain encompasses the issues of organization and coordination, the strategies and the power relationship of the different actors in the chain. A value chain exists when all the stakeholders in the chain operate in the way to maximize the generation of value along the chain. The value chain looks at the complex range of activities implemented by various actors (primary producers, processors, traders, service providers, etc) to bring a raw material to the retail of the final product.

In Cambodia, the value chain is suffering from low sanitary standards of inputs and products. There are 5 actors involved in the aquaculture value chain, it was fish farmers (pond and cage farmers), traders (fresh and processed fish), processors, retailers and consumers. Most of the extensive farmers sell the product directly to consumers, while semi-intensive ponds farmers sell their products to 16%, 6% and 78% to consumers, retailers' fresh fish and traders' fresh fish respectively. While only intensive pond farmer and cage farmers sell all their production directly to traders (Figure 2).

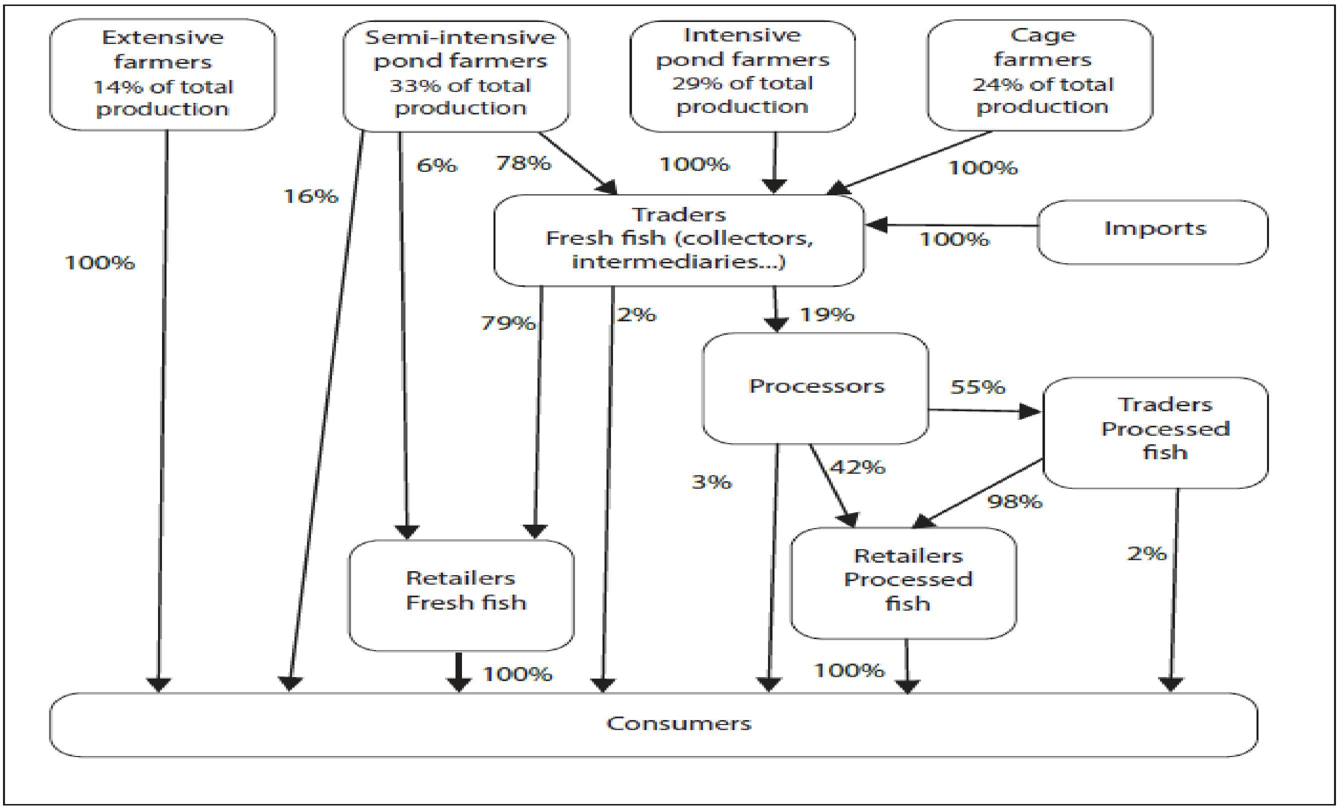

Figure 2: The product flows of the aquaculture value chain in Cambodia (Source: VCA4D, 2018)

Another studied indicated that small-scale fish raisers sell their products to collectors and traders and small scale fish processing. More than 90% of collected products by collectors and traders to local market and big city markets, while another less than 10% sell to small scale fish processors before selling to local market and big city markets. For Large scale fish raisers, they sell all their products to large scale fish processors and further sell to both local market and big city markets and export markets (DAI, 2007).

There is significant potential for growth and diversification of species and fish farming systems, in order to supply the domestic and regional markets more efficiently. But some major risks existed, it included competitive with imported fish, animal health and food safety, use of low-value freshwater capture fish for homemade feeds, pesticides from water body to product and vice-versa, lack of good aquaculture practices, lack of water, working conditions and nutrition and sanitation.

3.2. Aquaculture Production (Quantity and Trend)

Eastern Asia represents nearly 90% of the world production of aquatic animals (FAO, 2008). In Cambodia, the major share of the fish production comes from the cages and pens in the Tonle Sap (Phillips, 2002). Major supplies of fish come from freshwater capture fisheries, freshwater aquaculture and from imported fishes and fisheries products. The majority of the fish supply in Cambodia is from Freshwater capture fisheries but notably decreased from around 3% to 5% for the last 5 consecutive years. In contrast, the aquaculture production has increased sharply from 30% from 2019 to 2020 and drop to 4% in 2023. The total aquaculture production from 2019 to 2023 were ranged from 307,408 – 314,000 tonne (FiA, 2023). In general, the trend of total fish production almost stables for the five consecutive years (Figure: 3).

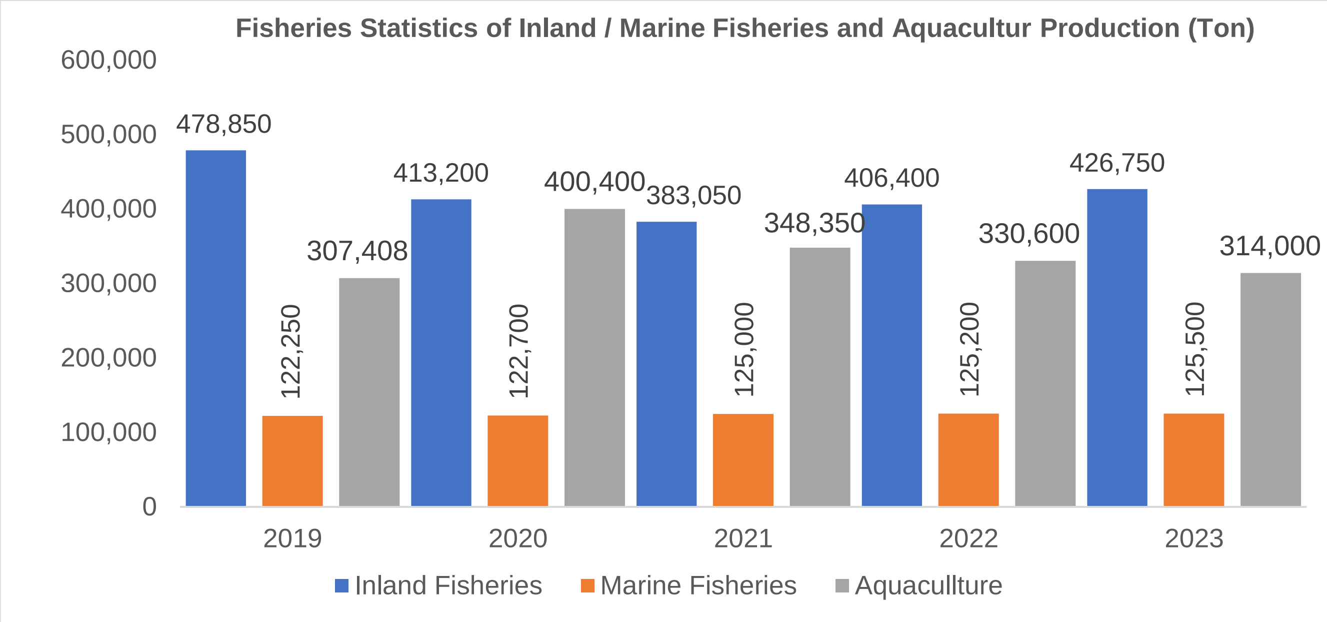

Figure 3: Fisheries production by category (Data source: FiA, 2023)

IV. Technology Implication of Aquaculture in Cambodia

41. Small-Scale Aquaculture

Small scale aquaculture seems to be steady during the decade, the small-scale farmers used more or less the same technologies in pond preparation, cage and pen preparation, rice-field preparation, fish aquaponic system preparation, fish seed selection, fish releasing and feeding technique and the more popular one today were raising fish inside the plastic tank and concrete tanks (including biofloc system). Seed selection are more developed for plastic and concrete tanks practices. The selection is based on the market demands, farmers changed from less market demand species to more demand of market. Water Quality checking were also be more concerned, during this decade, farmer used water quality test kits to measure water quality in their pond and some electronic material such as multi-parameters tool. Feed and feeding technique moved from using homemade feed to high protein content pellet feed and following feeding technique procedures. Typically, no structured management practices such as record-keeping, systematic feeding schedules, and regular health monitoring of stock, less access to extension services and technical training to improve management practices, less access to quality seeds, feed, and other necessary inputs, not better connections to markets and value addition. However, accessibility to the electricity in some areas of the country is limited. Therefore, to increase fish culture productivity of small scale fish farmer, RAS system by using solar penal (energy) may need to apply, combining with available feed material in their village.

4.2. Medium Scale Aquaculture

Medium scale aquaculture seems to be steady during the decade, the medium-scale farmers used more technologies like pond lining and water management systems (e.g., aerators), using Recirculating Systems in providing a controlled environment that minimizes water use and environmental impact, more intensive fish production in natural water bodies and maximizing space utilization in cage system. The operation typically employing selective breeding techniques to improve growth rates, disease resistance, and feed conversion efficiency in fish species, tools to select superior breeding stock and improve the overall quality of fish produced. Using of high-quality pelleted feeds that meet the nutritional requirements of various species, improving growth rates and health. Utilization of probiotics, and other additives to enhance gut health and boost immunity in fish, using diffused aeration or paddlewheel aerators to ensure adequate oxygen levels in ponds or tanks, implementing mechanical and biological filtration to maintain water quality by removing solids and toxic substances (e.g., ammonia). This scale has regular testing for parameters like pH, ammonia, nitrite, and dissolved oxygen to monitor and manage water quality effectively, vaccination against common fish pathogens to minimize disease outbreaks, implementing designated quarantine facilities for new stock to prevent disease transmission, some medium farms utilized sensors to monitor water quality, fish health, and feeding behavior in real-time, providing data-driven insights for management. Moreover, to reduce cost of production, most of farm applied solar penal energy during the water circulation and fill in and pump out.

4.3. Large Scale Aquaculture

In Cambodia, the large scale aquaculture was not far different from medium scale aquaculture, but have substantial initial investments in infrastructure, equipment, and technology, including advanced farming systems and facilities, utilization of sophisticated technologies for monitoring and managing water quality, automated feeding systems, and biosecurity measures. It may cultivate a wide range of species, including commercially valuable fish (such as Pangsius spp, tilapia, and catfish). Monoculture is common for species with high market demand, some large-scale operations may also implement polyculture to optimize resource use and enhance sustainability. Large-scale operations typically have structured management systems, often led by trained professionals who implement best practices in aquaculture, and use of data analytics for monitoring production, health management, and financial performance is common, allowing for informed decision-making and optimization of operations, often function as formal businesses with clear profit motives, often employing a larger workforce compared to small and medium-scale farms, and typically targets both local markets and international exports, contributing significantly to national economic development.

4.4. Main Source of Seed Supply

The existence of a competitive domestic fish seed production sector is widely regarded as essential for aquaculture development to occur successfully, as the availability of affordable, high quality seed is a key factor conditioning farm performance (Tran et al., 2021).

Surveyed hatcheries produced a total 26 million fingerlings in 2018, a relatively low total volume of production. For comparison, tilapia hatcheries in Thailand sold around 80 million fry per month in 2008 (Belton, 2012), and Vietnam produced more than 2 billion pangasius fingerlings in 2019 (VASEP, 2020). The number of fingerlings produced per surveyed hatchery in Cambodia ranges from 5,000 individuals to 7 million, with eighteen hatcheries producing fewer than 0.5 million fingerlings each year. The main species produced are tilapia, pangasius and silver barb, accounting for 40, 36 and 10% of fingerlings, respectively. This species composition differs considerably from that reported by surveyed farms.

Fish seed production is highly seasonal as rainfall determines the timing of stocking on farms, peaking in the monsoon months of July and August. Only 45% of hatcheries reported being able to meet demand for seed during the peak stocking period. The result with reference to the short peak in demand requiring production of large quantities of seed within a brief window, and limited production planning and no marketing strategies to reach new markets beyond their established networks.

Many hatcheries and nurseries face severe environmental constraints. Rain is the main source of water for local hatcheries, putting them at risk of water shortages. Local hatcheries also reported having been affected by severe drought in the recent past. Another constraint commonly found is the irregular rain that makes fish become sick or die.” However, hatcheries are regularly affected by floods, requiring fencing around ponds to avoid brood fish escaping and mixing populations. Half of nurseries also reported being affected by flooding. Linkages between hatcheries and nurseries are limited while most of the fish growth-out farmer bought fish fingerling without knowing the source of fingering. Moreover, nurseries do not usually contract Cambodian hatcheries as seed suppliers, as the supply of seed from local hatcheries is considered unreliable and expensive. Nurseries buy and sell seed with a short nursing period, averaging 28 days, and therefore operate more as fingerling traders than conventional nurseries. Most of the seed traded by nurseries is imported from Vietnam.

4.5. Feed Source Supply

Feed and, to a lesser extent, seed are the two major inputs for fish farming. Two types of feed are used: homemade feed and pelleted commercial feed. Almost all commercial feed is imported from Vietnam. Low value fish (often referred to as trash fish) from capture sources and seafood processing waste are being used as protein inputs into home-made feed. For seed, there are three main sources: local hatcheries (mainly carps, tilapias and barbs), imported from Vietnam (mainly pangasius, snakehead and clarias species), and wild. Significant numbers of snakehead fingerlings are imported informally.

No fish feed mill was operating in Cambodia at the time of the survey, but one local feed mill began to produce floating pellets in 2020. All floating pelleted fish feed sold in Cambodia at the time of the survey was imported, from Vietnam and Thailand. Six brands of imported floating pelleted fish produced by large feed companies are marketed through a network of retailers. Retailers sell feed mainly during peak farming season from July to December. This is somewhat higher than in neighboring Vietnam and Thailand, but does not appear excessive, considering the transport and transaction costs associated with importing feeds. In fact, given the relatively small size of the aqua-feed market in Cambodia, the presence of six international brands suggests a convenient market for international suppliers operating on a large-scale in neighboring countries, resulting in a reasonable level of competition.

Photo: The pellet feed imported from Vietnam

4.6 Technical and Structural Challenges to Aquaculture Development

Technical transformation would be required to achieve the ambitious policy targets set for Cambodia’s aquaculture sector. Most of constraints at the farm and sector scales, across technical, institutional, economic, and biophysical dimensions. At the scale of the production unit (farms, hatcheries, processors), the existence of technical and economic constraints is highlighted the main challenges. Moreover, the limited access to water on farms, the high price of feed and poor quality of seed, and the basic nature of most farming practices (Bengtson et al., 2016; Maredia et al., 2017; VCA4D, 2017; Richardson and Suvedi, 2018; Joffre et al., 2019).

However, three fundamental sector-wide structural challenges to the growth of Cambodia's aquaculture sector. First, there is limited regulation and lack of enforcement of the import of fish and fingerlings from neighboring countries. Prices of imported fish reflect their lower production costs, and it is suspected that fish that are unfit for export due to residues, or surplus to demand in major markets find an outlet in Cambodia (VCA4D, 2017). This issue is currently being addressed by the government with a temporary ban on imported aquaculture fish to support local industry (MAFF, Press release on January 08, 2021). However, the legality of this ban remains unknown, as Cambodia is part of the ASEAN community and trade barriers are subject to WTO treaties. Import controls would better be approached from a food safety and biosecurity perspective, to avoid unregulated imports of material of unknown quality. Similar issues arise from the import of large numbers of fingerlings of unknown origin, health status, and quality (Joffre et al., 2019). Second, there is no regulatory framework to control the quality of domestic farmed fish products. The absence of standards, quality certification, or traceability systems means that producers and processors have little incentive to upgrade their practices. In Cambodia, aquaculture innovation technology may vary spatial and temporal geographical areas. Most pond-based farms, and many hatcheries and nurseries, face annual drought and flood cycles. Although Cambodia is often depicted as a country with abundant water resources, many producers are affected by drought, often limiting production to the rainy season. However, groundwater is rarely used as a water source for pond farms and hatcheries, meaning that exploring methods, by using solar energy for pumping to ensure affordable groundwater access by fish producers could represent a key policy option. In addition to the survey reports of flooding of pond farms, hatcheries, and nurseries, in October 2020, a severe flood event occurred, impacting thousands of households, including numerous fish farms, resulting in thousands of dollars in losses to aquaculture farmers (CAST, 2020). This fact highlights the persistent vulnerability of the sector to flood, and the need for new innovation technology assistant and financial products such as aquaculture insurance as a risk mitigation tool for investors.

4.7. Investment Cost

Investing in aquaculture in Cambodia can be a profitable venture due to the country's rich water resources and increasing demand for fish. However, the investment costs can vary significantly based on several factors, including the type of aquaculture system, the scale of operation, and the specific species being farmed. Here are some key considerations regarding investment costs in aquaculture in Cambodia:

- Purchasing or leasing land suitable for aquaculture can vary in cost depending on location, size, and accessibility to water resources.
- Building ponds, cages, or tanks, as well as constructing necessary facilities (e.g., storage, processing, and administration buildings) can require significant investment.
- Water pumps, aeration systems, feeding systems, and any technology needed for monitoring and managing water quality and fish health.
- The cost of purchasing fish seeds or fingerlings, which can vary based on species and supplier.
- Regular feeding is a significant ongoing expense, and the cost will depend on the type and quality of feed used.
- Water supply, electricity, and possible fuel costs for transportation and equipment.
- Obtaining necessary permits and licenses from government authorities can involve costs and administrative fees.
- Investing in training and knowledge acquisition is essential to ensure sustainable and productive aquaculture practices.
- Depending on the operation's scale, there may be costs related to implementing environmentally sustainable practices and technologies.
- The investment incentives for aquaculture development in the country are limited and regulation of aquaculture production and input supply systems are weak.

In general, the investment costs in Cambodia's Aquaculture relatively high due to high costs for necessary equipment, materials and machineries. On the other hand, raw materials for fish feed composition were also produced from the high cost of investment.

4.8. Innovation Technical Expertise

There are very few technical experts working in the field. Here are some of the major challenges:

- Many local farmers and workers may lack formal training in modern aquaculture practices, leading to inefficient and unsustainable farming methods.
- Knowledge Transfer to ensuring that research and technical knowledge development by universities and research institutions effectively reach practitioners can be difficult.
- Access to modern aquaculture technology and infrastructure by technical experts are limited, particularly in rural areas.
- The wage of skilled labor for daily operations, feeding, maintenance, and monitoring were also high if comparing with the return from the investment.
- The knowledge of the production of more commercial aquaculture species and associated technical and disease issues is limited.
- Skills in modern post-harvest techniques are limited amongst the private sector in Cambodia.

4.9. Infrastructure

Infrastructure are important for aquaculture but there are several infrastructure-related challenges faced by the aquaculture sector in Cambodia:

- Access to quality water to have clean and sufficient water supply while some areas physical infrastructure such as yearly water supply and electricity is limited, which causes the production cost is relatively high comparing to neighboring countries.
- Inadequate irrigation and water management systems make it difficult for farmers to maintain optimal conditions for aquaculture, particularly during dry seasons.
- Poor road conditions can hinder access to markets, making it difficult for aquaculture producers to transport their products to consumers efficiently.
- Lack of cold chain logistics such as lack of proper refrigeration and transportation facilities increases the risk of spoilage, affecting the product quality and leading to potential losses for fish farmers.
- Lack of the designed infrastructure to withstand the impacts of flooding and droughts.
- Many aquaculture operations, particularly small scale holders do not have adequate plans or infrastructure to deal with natural disasters, leading to significant losses.
- Land and water availability for expanded aquaculture is poorly managed.

4.10. Aquaculture value chain (including market access)

Production has been growing in the last decade, whilst imports of farmed fish from Vietnam and Thailand remain high. Despite general availability of land and less polluted water in Cambodia, the value chain (VC) is suffering from low sanitary standards of inputs and products. Nevertheless, there is significant potential for growth and diversification of species and fish farming systems, in order to supply the domestic, regional and international markets more efficiently.

- The Understanding market demands and consumer preferences is crucial as many local fish producers may lack this knowledge, with limited technical support from relevant agencies.
- Poor engagement among the stakeholder in aquaculture sector, in term of weak links in the supply chain, including transportation and distribution, can hinder market access and profitability.
- Poor market infrastructure (like fish markets) that can hinder fair pricing and affect profitability for aquaculture farmers and lack access to timely market information, which can impact their decision-making and ability to respond to demand changes.
- Growing seasonal calendar is not proper plan, relating to the timely market information, which can impact their decision-making and ability to respond to demand changes.
- Electricity costs for aquaculture intensification and fish processing are high.

- Sanitary and phytosanitary (SPS) measures are not well integrated into production chains, and laboratory testing and certification systems are not well developed.
- There are few incentives for the private sector to enter into commercial post-harvest activities.

4.11. Regulatory and policy gaps

- The aquaculture sector is often hampered by unclear or inconsistent regulations, which can discourage investment and complicate compliance.
- Obtain permits and licenses can be time-consuming and challenging for both local and foreign investors.
- Limited governmental support in providing the necessary infrastructure, like research, technology transfer, and financial aid, hampers growth.
- Lack of cross-border collaboration among key players and the lack of cross border trade regulation and regulation implementation.
- Imports of inputs to the sector are poorly regulated.
- Feed and seed supplies to aquaculture are limited and poorly regulated.
- Neighboring countries already have established production and market systems which limit options for Cambodia's market access.

4.12. Environmental concerns

- Medium and large-scale aquaculture applied hormone, disease prevention medication and other chemical treatment so that environmental safeguard should be considered.
- Genetic overlapping and diseases needs to be controlled avoiding escape to natural water bodies.
- Pollution, and habitat destruction can impact aquaculture productivity
- Impact of climate change leads to change in water temperature, availability, and salinity can affect aquaculture systems, requiring adaptability and innovative solutions or species could tolerant to the change.

4.13. Access to finance

- Limited funding for aquaculture research can hinder the development of local solutions to specific challenges faced.
- Small-scale farmers, particularly people on the floating village often find it difficult to secure funding for investments in improving their aquaculture systems.
- Both local and foreign investors may be hesitant to invest in aquaculture due to perceived risks associated with the sector.
- Limited access to credit and financial services can prevent farmers from investing in necessary infrastructure improvements or expansions.
- The requirement for monthly repayment of commercial loans is a major problem for many aquaculture borrowers because they are without income up to the time of harvesting of the fish crop.

V. Future Outlook for Innovation Aquaculture Development in Cambodia

5.1. Government and policy support

Following the National Aquaculture Development Strategy-NADS (2016-2030), outlines key priorities and future investment requirements in aquaculture. However, knowledge about the current status of the sector is lacking (Joffree et al., 2019). There were 7 strategic objectives to guide the development of the aquaculture sector:

- To increase access to high quality seed, both government and private hatcheries for a range of species in demand in local, regional and global markets.
- To increase access to sufficient and consistent supplies of high quality water, and to reduce flood risks.
- To ensure widespread availability of sustainably sourced, reasonably priced, high quality feed suitable for a range of species.
- To improve efficiency, profitability and sustainability of aquaculture production through increased knowledge, skill and organization.

- To maintain environmental quality and minimize loss from disease.
- To increase the quality and value of production.
- To facilitate access to credit as appropriate to the needs, potential and risks associated with aquaculture development.

The focus is the development of a diversified aquaculture industry which includes both traditional small-scale fish farming, which involves some 40,000 households countrywide, and more commercially oriented small, medium and large sized farming enterprises. Moreover, Department of Aquaculture Development of Fisheries Administration are promoting and strengthening the implementation of Good Aquaculture Practices (GAPs) through technical support from ITs (International tender package).

5.2. Sustainability and Market Opportunities

Sustainability in Cambodia's aquaculture sector presents a range of market opportunities, particularly given the country's growing demand for food and increasing focus on sustainable practices. However, aquaculture is playing important role in providing and sustainable local food security in the whole country. Current effort of the Fisheries Administration has focus on:

- Promoting organic fish farming methods, such as the use of natural feeds and avoiding antibiotics. For instance, the integration of traditional practices like rice-fish farming offers a sustainable model that boosts biodiversity and soil fertility.
- Enhance eco-tourism. Fish farms that practice sustainable methods can attract tourists looking for authentic experiences. For example, a farm offering tours, hands-on fishing experiences, and educational programs about sustainable practices could generate additional income.
- Developing value-added products (e.g., fish sauces, dried seafood) can help local producers tap into both domestic and international markets. For example, a local company could create premium fish sauce using traditional fermentation methods, appealing to both local consumers and niche markets abroad.
- Cambodian aquaculture businesses can pursue certifications to access international markets and improving their market competitiveness.
- Developing resilient aquaculture systems.
- Innovations like integrated multi-trophic aquaculture could help farmers diversify their production, risks reduction and additional income.
- Promoting local fish consumption to support local economies and enhancing community well-being and sustainability.

5.3. Smart Aquaculture technologies

Smart aquaculture technologies are revolutionizing the way aquaculture is introduced through the CapFish Aqua in Cambodia, enhancing efficiency, sustainability, and productivity. Here are some key technologies and their potential impacts:

- Current Using Sensors and monitoring system is limited, both small medium and large scales. For example: using sensors to monitor water quality (temperature, pH, dissolved oxygen) in real-time. This helps farmers make immediate adjustments to maintain optimal conditions, leading to healthier fish and higher yields. For instance, a farmer using a system like SmartFarm can receive alerts via smartphone if water parameters fall outside the ideal range.
- Using automated feeders programmed to dispense feed at specific times and quantities can reduce waste and improve feed conversion ratios, saving costs and minimizing environmental impact.
- Utilizing AI for predictive analytics, farmers can forecast growth rates, mortality, and disease outbreaks. For instance, a platform like Fish Farming Technologies could analyze historical data to recommend optimal harvest times, enhancing profitability.
- Using drones for aerial surveillance of large aquaculture farms, monitoring stock health and environmental conditions. This technology allows for quick assessments of pond conditions and identification of issues like algal blooms or unauthorized fishing activities.

- Implementing blockchain technology can enhance traceability in the supply chain, ensuring that consumers know the origin and sustainability of their products.
- Using Recirculating Aquaculture Systems technology allows for fish farming in a closed-loop system, minimizing water usage and environmental impact. In urban areas, this technology can enable fish production in small spaces while reducing the risk of disease and pollution.
- Using Mobile apps to provide farmers with access to best practices, market prices, and weather forecasts.
- Implementing Integrated Multi-Trophic Aquaculture systems combine different species in a single farming operation, where the waste from one species serves as nutrients for another. This reduces waste and improves overall farm productivity, a model being tested in several Cambodian farms.

VI. Conclusion and Recommendation

Aquaculture technology innovation in Cambodia is limited. Most of the common practices found for the whole country is traditionally for small whereas most of medium and large scale commonly practices by learning from farmer to farmer. Recirculating system (RAS) has been applied for medium and large scale, particularly snakehead pond culture and cage culture around the Tonle Sap Lake during the dry season when water quality dropped down. Moreover, costs of production is comparatively high comparing to neighboring countries in Vietnam and Thailand as technology of solar energy is limited and could not afford by the local fish farmer. However, the commercial fish seed and feed production in Cambodia is still at a developmental stage, and is likely to take a few years before it can be fully operationalized. Thus, the seed and feed supply will continue to rely on imported products for the foreseeable future. However, the feed producers that are conducting their own experiments into fish feed need technical and financial assistance to develop new product lines that can eventually enter the market. To improve the current status of aquaculture technology in Cambodia, the following intervention are:

- Focus the project interventions initially on existing producer clusters in selected locations and key species, i.e. Pangasius and snakehead, and use an “incremental innovation approach” to gradually upgrade management practices of producers, particularly feeding. For example, providing alternative feed for snakehead producers when the supply of trash fish is low would give an opportunity for the producers to test pellet feed and encourage them to reduce the unsustainable use of trash fish.
- Irrigation scheme and accessibility to the electricity should be proper set up by subsidization from the government.
- Focus its technical intervention initially to support a large number of pond-based producers who can improve productivity through relatively simple changes in water management and pond preparation. These elements of the aquaculture practices can be easily improved (using lime, fertilizer) without significant investment cost and support an increase in productivity. This type of technological package needs to go in parallel with an improvement in feeding regimes.
- The improvement environmental friendly, encourage fish farmer to implement Good Aquaculture Best Practices, that can later inform the future national GaqP to be developed by the Fisheries Administration.
- Introduce model farms, including both ponds and cages, to demonstrate improved production techniques as well as effective business models. A wide range of technologies and practices need to be demonstrated, including feeding practices, fingerling selection, water management, and fish disease control. The proposed model farms need to be nested within existing hatcheries and nurseries networks where the role of feed distributors, hatcheries, and nurseries as private extension services can also be enhanced and serve as a model for replication in other locations.
- Supporting the aquaculture producers and hatchery operator to develop good innovation technology and their business plans by including Small Indigenous Fish Species (SIS) breeding technology.
- Support climate change adaptation by identifying key communes and districts where access to water is a constraint and/or ponds are frequently affected by flooding. The adoption of short cycle species is not yet common in Cambodia. In these specific areas the project should develop a “climate smart business model” based on short cycle species.

- The poly-aquaculture homestead pond innovation for the household or community-scale system should be scale up and expanding the aquaculture technologies into additional high-potential areas in Mekong Deltas of Cambodia, some areas around Tonle Sap lake and costal area.
- Scale up fish farming system and increasing household beneficiaries including: aquaculture homestead pond, Small & Medium Enterprise (SME) intensive pond culture and rice-fish culture.
- Together with stakeholder to conduct the comprehensive research on rice-prawn culture methods, technologies and innovation from initial studies to commercial implementation.
- Implement training program and organize study visits to share research finding on aquaculture innovation technologies with farmers, fisheries and aquaculture students and relevant institution.

The Aquaculture Value Chain

Demand for quality aquaculture fish produced in Cambodia is high and increasing, but the current production level and the capacity of local producers is too low to meet this demand. Aquaculture fish produced in Cambodia currently represents 54% of the volume traded by the collectors and wholesalers surveyed by the study, while capture fisheries and imported aquaculture fish make up the rest. Consumer preferences in Cambodia rank capture fish the highest, aquaculture fish from Cambodia the second, and imported aquaculture fish the lowest; however, there is no system to clearly distinguish the origin and assure the quality of these products when it reaches the consumer market. Reliable mechanisms for improving traceability and quality standard such as third party certification, or “block-chain” mechanisms involving digital technology need to be established and can create premium prices for products that meet certain consumer preferences and market niches. Aquaculture fish can fetch the highest prices when sold alive. Thus, hygienic standards and fish handling/transportation technologies of post-harvest operators need to be improved as a priority, through the provision of suitable equipment and procedures. Fish buyers and traders are often the only source of market information for producers, and thus have a distinct advantage in the value chain, over the producers. There is no information sharing mechanisms at provincial or national levels to facilitate access to reliable and up-todate information on aquaculture inputs and product prices. Many producers are also tied to particular buyers through debt. Breaking the cycle of these patron-client relationships, which are very common in Cambodia and are often built on long-term personal relationships, is challenging. However, improved access to other financial services and alternative models of trading and marketing can improve the negotiating position and profit of producers in the value chain.

The linkages and flows of trash fish between capture fisheries and aquaculture should be investigated further and volumes estimated more accurately. Finally, we did not assess financial performance of the different production system and compare the competitiveness gap with similar production systems operating in neighboring countries. This study highlights that Cambodia’s aquaculture production systems remain constrained by technical, institutional, and economic factors that limit their performance and competitiveness. To achieve the transformation of the aquaculture sector, several macro-scale structural interventions are required, among which the development of a regulatory framework for regulating imports of fish, fingerlings and inputs to Cambodia is key. This also encompasses developing value chain standards to differentiate imported and local farmed fish and respond to increasing demand for locally raised fish. Commercially oriented fish farming will grow only with perennial access to water and if flood risk is mitigated. Considering the effect of hydropower development on flood patterns (Basist and Williams, 2020), the overall hydrology of the country and climate change predictions in the region (ICEM, 2013) that forecast higher temperatures and longer dry seasons, affordable access to groundwater may be required for aquaculture to grow further.

In addition, aquaculture cannot be established, nor expand everywhere in the country and investments should be prioritized to target aquaculture clusters in suitable areas, where support systems, producers and concentrations of other value chain actors exist and can be supported. In terms of aquaculture inputs and farming practices, our analysis shows that feeding regimes are still heavily dependent on trash fish from capture fisheries, which are increasingly scarce. The transition toward the use of formulated feeds will be facilitated by access to good quality pelleted feeds at a competitive price, and to knowledge to support efficient feeding practices. Our recommendations regarding feed include creating an enabling environment (e.g., a regulatory framework, accurate information on market demand, and market information systems) for feed producers to invest in local production lines. A widespread shift of feeding regime will also require the transformation of support services, with more accessible sources of information to facilitate behavior change among producers toward more sustainable practices using less trash fish. In addition, the ecological intensification of pond systems producing non-carnivorous species through semi intensive feeding regimes based on pond ecology, green water, and rice bran could also support increased production. Skilled labor is required facilitate a transition to more efficient value chains and production systems.

Trained professionals with practical skills will be needed to provide support services to producers and support sectoral development. Donor-funded projects initiated since 2020 are training farmers and private service providers and supporting access to knowledge. However, additional support and more fundamental changes in access to education, knowledge and support services for the sector are required to support its transformation.

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