AQUACULTURE PRODUCTION AND EMPLOYEE WELLNESS BETWEEN BRACKISH WATER AND FRESHWATER FARMERS IN PENANG STATE

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by

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LIST OF SYMBOLS

p	Probability
M	Mean
SD	Standard deviation
χ^2	Chi square
Y	Dependent variable
X	Independent variable
a, B	Regression coefficients

LIST OF ABBREVIATIONS

FAO	Food and Agriculture Organization
Ha	Hectare
USD	United States Dollar
RM	Ringgit Malaysia
ETP	Economic Transformation Plan
QoL	Quality of Life
MT	Metric Tonnes
Km	Kilometers
MoA	Ministry of Agriculture
DoF	Department of Fisheries
EPP	Entry Point Projects
NKEA	National Key Economic Area
RAS	Recirculating Aquaculture Systems
pH	Potential of Hydrogen
GDP	Gross Domestic Product
AIZ	Aquaculture Industrial Zones
NAFP	National Agro-Food Policy
NAP	National Agriculture Policy
GNI	Gross National Income
COVID	Coronavirus Disease
GAqP	Good aquaculture practice
myGAP	Good Agriculture Practice Malaysian
DoE	Department of Environment
EIA	Environmental Impact Assessment
ASEAN	Association of Southeast Asian Nations
PRP	Preliminary Farm Certification Program
SWQM	Smart Water Quality Monitoring
WSN	Wireless Sensor Network
IoT	Internet of Things
LBP	Lower Back Pain
AGP	Antibacterial Growth Promoters

DASS-42	Depression, Anxiety and Stress Scale-42
RSES	The Rosenberg Self-Esteem Scale
GHQ-12	General Health Questionnaire
FA	Factor Analysis
EFA	Exploratory Factor Analysis
KMO	Kaiser-Meyer-Olkin
B40	Bottom 40%
M40	Middle 40%
T20	Top 20%
ICT	Information and Communication Technology
MARDI	Malaysian Agricultural Research and Development Institute
NGO	Non-Governmental Organisations
CFA	Confirmatory Factor Analysis
PCA	Principal Component Analysis
ML	Maximum Likelihood
PAF	Principal Axis Factoring
USM	Universiti Sains Malaysia
IPS	Institut Pengajian Siswazah
SPSS	Statistical Package for Social Science

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PENGELUARAN AKUAKULTUR DAN KESEJAHTERAAN PEKERJA ANTARA KUMPULAN PETANI AIR PAYAU DAN AIR TAWAR DI NEGERI PULAU PINANG

ABSTRAK

Pengenalan: Akuakultur merupakan sektor pengeluaran makanan penting untuk meningkatkan indeks keselamatan makanan dan pemakanan global. Kemampanan industri akuakultur sangat bergantung kepada ruang, persekitaran, ekologi, ekonomi, industri, tingkah laku manusia dan dasar. Walau bagaimanapun, industri akuakultur mengalami kekurangan bimbingan profesional dan kecekapan teknikal, dan penggunaan teknologi mampan kurang dilaporkan. Kajian keratan rentas ini menilai kesediaan penggunaan pihak berkepentingan akuakultur, tingkah laku yang dirasakan dan halangan penentu ke arah teknologi akuakultur yang mampan. Kajian ini juga mengkaji aduan kesihatan, status mental dan kualiti hidup pekerja akuakultur. **Metodologi:** Senarai ladang akuakultur berdaftar diperolehi daripada Jabatan Perikanan Negeri Pulau Pinang. Susulan itu, surat jemputan dihantar secara rasmi kepada semua pemegang taruh akuakultur yang tersenarai, diikuti dengan panggilan telefon individu dan taklimat penyelidikan. Pemilik akuakultur ditemuramah, dan maklumat berkenaan pengeluaran, jualan, pengurusan, kesediaan penggunaan teknologi, dan halangan telah dikumpulkan. Aduan kesihatan pekerja akuakultur dikumpulkan, dan status kesihatan mental dinilai dari segi kemurungan, kegelisahan, tekanan dan harga diri. Kualiti hidup pekerja akuakultur dinilai menggunakan soal selidik berstruktur. **Keputusan:** Kajian ini melibatkan 88 (84.6%) orang pemilik akuakultur air payau dan 16 (15.4%) orang pemilik akuakultur air tawar. Seberang Perai Utara (8.7%) mendominasi pengeluaran spesies akuakultur air tawar, manakala

Seberang Perai Selatan mendominasi industri akuakultur air payau (69.2%). Input yang biasa digunakan dalam pengeluaran penternakan ikan melibatkan kos persediaan (100%), operasi dan penyelenggaraan ladang (98.1%), perkhidmatan teknikal (97.1%), makanan ikan komersial (96.2%), buruh sewa (94.2%), kemudahan lain (91.3%), kos pengangkutan (89.4%), kapur abu sejuk (47.1%), jaring (46.2%), benih ikan (41.3%), pagar (19.2%), stok hapa (11.5%) dan baja atau kompos (4.8%). 87% daripada pemilik akuakultur bersetuju bahawa mereka menerima maklumat yang mencukupi berkaitan amalan akuakultur. Hanya 26.9% pemilik akuakultur pernah menghadiri latihan sebelum mengendalikan ladang ikan. 91% pemilik akuakultur menyatakan hasrat untuk mengaplikasikan teknologi baru, bagaimanapun, niat itu terhalang oleh kekurangan kesedaran dan sumber maklumat. Analisis multivariat menunjukkan bahawa teknologi maklumat adalah halangan yang paling ketara untuk digunapakai. Kedua-dua pekerja penanaman air payau dan air tawar berhadapan dengan keletihan, kesakitan dan insomnia, di mana seramai 48%, 40.4%, 26% dan 24% daripada mereka menghadapi kemurungan, kebimbangan, tekanan dan harga diri yang rendah. Sebanyak 3.4% pekerja air payau mengalami kualiti hidup yang buruk. Aduan sakit leher/bahu/lengan ($F = 13.963$; $p < 0.001$), sakit belakang ($F = 10.974$; $p < 0.01$), sakit tangan/pergelangan tangan ($F = 8.041$; $p < 0.01$), sakit lutut/pinggul ($F = 12.910$; $p < 0.01$) dan insomnia ($F = 10.936$; $p < 0.01$) dikaitkan dengan kualiti hidup yang buruk. Dari segi kesihatan mental, harga diri ($F = 4.157$; $p < 0.05$) adalah berkaitan secara negatif dengan skor kualiti hidup. **Kesimpulan:** Kajian ini mencerminkan kepentingan perancangan dan strategi berterusan dalam kalangan pemilik akuakultur dan kerajaan untuk mengkaji semula amalan pengeluaran ikan yang mampan. Kesihatan dalam kalangan pekerja akuakultur adalah membimbangkan, dan ia menekankan keperluan untuk menyusun strategi intervensi.

AQUACULTURE PRODUCTION AND EMPLOYEE WELLNESS BETWEEN BRACKISH WATER AND FRESHWATER FARMERS IN PENANG STATE

ABSTRACT

Introduction: Aquaculture is seen as an essential food-producing sector for improving global food security and nutrition indices. The sustainability of the aquaculture industry depends strongly on the space, environment, ecology, economy, industry, human behaviour and the policy. Nevertheless, the overall aquaculture industry inherent lack of professional guidance and technical efficiency, and the intention of sustainable technologies utilization is often underreporting. This cross-sectional study evaluated the aquaculture stakeholders' adoption readiness, perceived behaviour and determinant barriers towards sustainable aquaculture technologies. The study also examined the health complaints, mental status and quality of life of aquaculture workers. **Methodology:** A list of registered aquaculture farms was obtained from the Penang State Fisheries Department. Subsequently, an invitation letter was issued officially to all the listed aquaculture stakeholders, followed by individual telephone calls and research intention briefing. Aquaculture stakeholders were interviewed, and information about production trend, sales, management, technology adoption readiness, and barriers were gathered. The aquaculture workers' health complaints were collected, and mental health status was evaluated as means of depression, anxiety, stress and self-esteem. Self-perceived quality of life was assessed using a structured questionnaire. **Results:** The study involved the participation of 88 (84.6%) brackish water and 16 (15.4%) freshwater aquaculture stakeholders. North Seberang Perai (8.7%) dominated the cultivation of freshwater aquaculture species, while South Seberang Perai dominated the brackish water aquaculture industry (69.2%). Commonly used inputs in fish farming production involved the setup cost (100%), farm operations and maintenance (98.1%), technical services (97.1%), commercial fish feed (96.2%), hired labour (94.2%), other facilities (91.3%), transportation cost (89.4%), lime (47.1%), net (46.2%), fingerlings (41.3%), fencing (19.2%), stocking hapa (11.5%) and fertilizer or compost (4.8%). 87% of the stakeholders received adequate information related to aquaculture practice. It was interesting to note that only 26.9% of the aquaculture stakeholders attended training before operating fish farm. 91% of the aquaculture stakeholders expressed their intention to adopt new technology, however, the intention was hampered by a lack of awareness and information resources. Multivariate analysis revealed that technological information was the most determined barrier for the adoption. Both brackish water and freshwater cultivation workers were confronted with fatigue, pain and insomnia. Up to 48%, 40.4%, 26% and 24% of them were facing depression, anxiety, stress and low self-esteem, respectively. A total of 3.4% of the brackish water aquaculture workers were having bad quality of life. The complaints of neck/shoulder/arm pain ($F = 13.963$; $p < 0.001$), back pain ($F = 10.974$; $p < 0.01$), hand/wrist pain ($F = 8.041$; $p < 0.01$), knee/hip pain ($F = 12.910$; $p < 0.01$) and insomnia ($F = 10.936$; $p < 0.01$) were correlated with bad quality of life among the workers. For mental health status, self-esteem ($F = 4.157$; $p < 0.05$) was found to be negatively correlated with quality of life.

Conclusion: This study is important to inform the aquaculture stakeholders and policy makers that continuous planning and strategies are warranted to review the management practise for sustainable fish production. The health concern among the aquaculture workers is alarming, thus pressing a need to strategise interventional measures.

CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter is divided into several sections to illustrate the aim of this research. The first section presents the introduction to the research area, while the next section provides a brief research background about the current aquaculture development in Malaysia. Then, aquaculture trends, health complaints, mental status and quality of life among the aquaculture farmers are discussed, followed by the development of research questions and objectives. Finally, the significance of study, research scope, and the definitions of key terms, are clearly explained.

1.2 Introduction

Aquaculture has been the world's fastest-growing food production sector for the last two decades (FAO, 2018). Global aquaculture production has reached 106 million tonnes in 2015, with 76.7 million tonnes contributed by aquatic animals, while the rest is coming from aquatic plants, with an average growth percentage of 6.6 % since 1995 (FAO, 2017). This positive trend is projected to continue as the aquaculture sector plays a huge role in contributing to food security and poverty alleviation (Arshad et al., 2022). Indeed, aquaculture activity relieves some pressure on wild aquatic resources, creates jobs, enhances livelihoods along the value chains and improves human nutrition in a number of underdeveloped and developing countries (Béné et al., 2016; Little et al., 2016; Golden et al., 2017; Rashid et al., 2019; Nasr-Allah et al., 2020; Ragasa et al., 2022).

The fishery sector has been playing pertinent roles as the major supplier of animal protein to the Malaysian population, with aquaculture farming serving as an important economic driver for the nation. In 2017, Malaysia has recorded total fishery production amounting to 1.7 million tonnes, including close to 1.5 million tonnes from capture, and 0.2 million tonnes from aquaculture (excluding seaweeds). In addition, Malaysia has produced 0.2 million tonnes of farmed seaweeds as the world's seventh largest producer, and ranked in third place for tropical carrageenan seaweed farming (FAO, 2022). Collectively, the local aquaculture sector produced 391,000 tonnes of cultivated organisms, with an economic value of over USD 700 million, accounting for about 0.2% of Malaysia's gross domestic product (GDP) in 2019 (Azra et al., 2021).

Aquaculture involves the cultivating activities of freshwater and saltwater populations under controlled conditions. Aquaculture farmers culture a wide variety of species, including the saltwater, brackish water and freshwater varieties, mostly prawns, fish, shellfish, finfish, cockles, abalones, oysters, crabs and others (Leng et al., 2020). The growth of brackish water and freshwater cultivation is highly correlated with the domestic and international demands. The cumulative aquaculture production in 2020 reached 400,017 metric tonnes (MT), with a wholesale value of RM 3,114,731. The brackish water culture system contributed 77.3 % to the total aquaculture production, as dominated by the cultivation of bivalve mollusks, shrimps, giant tiger prawns and marine fish species (FAO, 2013; Sampantamit et al., 2020; DoF, 2021; Kurniawan et al., 2021). The freshwater aquaculture activities usually involve the breeding and raising of aquatic animals such as the tilapia, catfish and carp in freshwater lakes, ponds, rivers or even reservoirs for economic purposes (Li & Liu, 2019). In 2020, aquaculture sector in Malaysia employed 0.13 % of the total workforce (14.96 million people) (Statistica, 2021). The farming characteristic of the brackish water and freshwater aquaculture system in Malaysia is shown in Table 1.1.

Table 1.1: Farming characteristics of the brackish water and freshwater aquaculture system in Malaysia

Characteristic	Brackish Water Cultivation	Freshwater Cultivation
Human resources	7%: brackish water and floating net-cage culture in the lagoons and coastal waters 6%: brackish water pond culture systems for black tiger shrimp and marine fish hatcheries 4%: bivalve mollusk culture 3%: seaweeds cultivation	70%: freshwater pond and concrete tank culture system 10%: floating net-cage culture in lakes, reservoirs, ex-mining pools and freshwater lagoons
Cultured species	Seaweeds, white leg shrimps, sea bass, tiger shrimp, cockles, grouper, red snapper, mangrove snapper, horse mackerel, milkfish, oysters, mussels and others	Red tilapia, freshwater catfish, river catfish, Labeo rohita, black tilapia, bighead carp, river carp, common carp, Javanese carp, grass carp, giant freshwater prawn, snakehead, giant snakehead and others
Most profitable species	White leg shrimps	Red tilapia
Production	144,189 tonnes	49,951 tonnes
Size	17,357 ha	4769 ha
Practices/systems	Ponds, cages and raft systems for mussel and oyster Bottom culture for cockle Long line for seaweed	Ponds, used-mining pools, tanks, cages and pen culture systems
Market and trade	Singapore, Taiwan, China and Hong Kong: barramundi, groupers, crabs, black tiger prawns, white leg shrimps Europe Union, Japan, United States of America and Australia: black tiger prawns and white leg shrimp are exported as block frozen or as value added products	Domestic consumption
Company operation years	6 to 10 years	≤5 years
Number of employees	20,262	15,719
Company size (no. of workers)	1–10	1–5
Income (per worker per month)	≥RM2,000	≤RM1,500

Source: DoF, 2019; Roslina, 2018; FAO, 2022

Quality of life at work refers to the physical, technological, psychological, and social aspects of work that are in line with the ideals of healthier organisation and are connected to employees' satisfaction in a secure and enjoyable work environment (Junior et al., 2020). To ensure the sustainability of aquaculture as a whole, it is crucial to emphasise the value of quality of life (Abubakar & Attanda, 2013). Quality of life for aquaculture workers is often poor, they may face long hours, low wages, hazardous working conditions, and limited access to healthcare and education (Frank et al., 2013).

The majority of aquaculture workers worldwide work in precarious positions and come from vulnerable populations. Fisheries industries have the highest incidence of work-related injuries and illnesses and there are many factors that can affect the quality of life and well-being of aquaculture workers (Watterson et al., 2019). The poor quality of life for aquaculture workers has a number of negative consequences that can lead to health problems, poverty, social exclusion, and violence. It is essential to remember that factors such as the nature of the job, organisational change, and workplace pressure all contribute to high levels of illness. Previous research suggested that in order to effectively address worker well-being, accurate information about the factors that contribute to the problem and the interventions that help improve worker health performance is required (Hsu & Kernohan, 2006). By having good quality of life, it will lead to better well-being of the workers and society. Thus, management must pay attention to employees' well-being as strong workforce will benefit organization (Noor & Abdullah, 2012).

1.3 Research Problem

Aquaculture has been recognized as an important sector for Malaysia's economic development. Economic Transformation Programme (ETP) 2010-2020, with an objective to transform a traditionally small-scale, production-based sector into a large-scale agribusiness industry that contributes to economic development and sustainability based on an integrated and market, and centric model that emphasises on economies of scale and value chain integration (Pemandu, 2010). However, the lack of livelihood asset, either in the form of physical or human assets, particularly in terms of knowledge, access to information and experience is evident, as fish farmers often ignore some aspects of environmentally sustainable conservation (Roslina, 2009). The aquaculture industry is currently facing the issue of production sustainability, employment of improved technology, concept of eco-friendly and food safety regulations. Among the constraints were education and knowledge, human greed, irresponsible, short-sighted activities, small farm size and investment, uprising cost of production, weak legislation and enforcement (Othman, 2008).

In the past, obsolete technologies and insufficient waste management systems in aquaculture contributed significantly to the degradation of the aquaculture environment (Cao et al., 2007). There have been less awareness and interest in developing technologies to reduce environmental problem. Managing sludge is one of the biggest concerns as the conventional method is time consuming and requires high cost. Hence, research is on its way to explore the potential of bioremediation in reducing and eliminating highly toxic contaminants in aquaculture sludge for a better future ahead. With the aforementioned, there is a need to explore the current aquaculture practice from the aquaculturists' point of view, ranging from the aquaculture systems, investment and affordability, socio-economic constraints, compliance to the aquaculture legislation and policy, readiness to accept modern aquaculture waste treatment and unfavourable barriers or challenges that threatened the sustainability of the industry.

Understanding the nature of cultivation between brackish and freshwater is vital for the development. The selection of an appropriate site, the characteristics of the soil, the quality of the water, the design of the facility, the water supply structures, and the water sources are just a few of the factors that affect how well a fish hatchery can function (Saraswathy et al., 2015). The fact that every species has unique requirement for physical and chemical needs is also important (Toni et al., 2019). Delve into the particular needs of each environment, aquaculture operations can maximise production, minimise risks, and ensure long-term success in both brackish and freshwater settings.

In term of employee welfare, the distinction between brackish and freshwater aquaculture is vital due to the variations of challenges particular to each. According to previous study, wide range of occupational hazards are caused by the diversity of aquaculture settings and cultivation techniques (Fry et al., 2019). Factors that may affect aquaculture workers include geography, habitat destruction, the type of cultivation practise, the capacity of natural systems to absorb waste, water consumption, wastewater generation and treatment, the types of chemicals used as feed and medicines, and geological and hydrological conditions (Senarath & Visvanathan, 2001). It is essential to recognise and address the special issues that arise in brackish and freshwater environments in order to maximise fish production and guarantee the welfare of aquaculture workers. Therefore, examining various cultivation groups can aid in identifying the variables influencing sustainable development and aquaculture management (Weitzman, 2019).

In 2019, the Department of Occupational, Safety and Health (DOSH) has investigated 274 occupational accidents involving workers in agriculture, fisheries and forestry in Malaysia (The sun daily, 2019). In particular, fishing activities have been reported to show high occupational fatality rates, but injuries and illnesses to people working in its sub-sectors, aquaculture and fish farming, are not well understood (Kaustell et al., 2019). Despite the promising aquaculture development, the aquaculture industry also poses underreported environmental threats and health risks (Safiih et al., 2016; Ngajilo & Jeebhay, 2019; Thorvaldsen et al., 2020). According to Myers et al. (2013), drowning, electrocutions, falls from elevation, slips and trips, falling objects, needle stick injections, roadway collisions, strains and sprains, spine wounds, impalements, equipment overturns, dust inhalations from feed, net entanglements, boat or vehicle battery explosions and burns are among the top 15 aquaculture-specific occupational hazards as these activities necessitate specific practices (De Oliveira, 2017). Consequently, long-term exposure towards the hazards and risk resulted in chronic illness, injuries and health complaints among aquaculture workers (Kaustell et al., 2019).

For the past several decades, medical professionals, researchers and policy makers have been paying attention to the health implications of mental disorders (Hagen et al., 2019; Kaur & Kaur, 2018). Specifically, stress has dominated the literature as one of the most broadly researched psychosocial constructs, mainly in the work-related stress area. Work-related stress is defined as a conflict when the demands of work are high, and the worker is confronting difficulties to manage, control or cope with that stress. For aquaculture farmers in particular, physical and ergonomic exposures are very common, and workers reported psychosocial exposures including stress and a lack of control in their workday (Thorvaldsen et al., 2020).

The quality of life for aquaculture workers requires special attention because it has a significant impact on their productivity, health, and safety as they deal with numerous risks associated with working in an aquatic environment. Shift work, high demand and low control situations, and stressful work environments have all been associated with work-related stress that accompanies psychological and physical symptoms, and it affects a person's quality of life (Mert & Ercan, 2015).

By putting a priority on safety measures and encouraging a healthy work environment, workers can reduce the likelihood of accidents and the related costs, such as missed work days, medical bills, and potential legal problems. This also helps workers maintain their health and quality of life as well as their financial security (Durborow & Myers, 2016). Improvements of husbandry practise must be implemented for ensuring workers livelihoods and improve their quality of life. Such improvements not only contribute to their overall well-being but also enhance their capacity, leading to increased fish production and income (Kumaran, 2003).

To date, approximately 149,949 workers are involved in the fisheries industry, where 20,149 culturists are engaged to the aquaculture industry in Malaysia (Agrofood Statistics, 2019). Despite all its current recognition and relevance, several key health challenges must be addressed in order to enable sustainable aquaculture industrial growth. However, to the best of our knowledge, the study of health complaints among the workers in brackish water and freshwater aquaculture are comparatively under-researched. Additionally, there have been no scoping studies to examine the mental health status among the aquaculture farming communities in Malaysia.

Overall, the research focuses on the challenges faced by aquaculture production in Penang State, specifically comparing brackish water and freshwater farmers. The key challenges identified include the lack of technology adoption, inadequate education and knowledge, limited investment due to small farm sizes, rising production costs, and weak regulatory enforcement. Additionally, the study examines the intention and barriers related to adopting aquaculture technology, highlighting issues such as the use of outdated technologies that harm the aquaculture environment, insufficient knowledge and access to information hindering industry progress. Furthermore, the research explores the health risks, mental well-being, and overall quality of life of aquaculture workers. It underscores the underreported environmental threats and health risks posed by the aquaculture industry and emphasizes the lack of prior investigations into the mental health status of aquaculture workers in Malaysia.

1.4 Research Objectives

The objectives of the study are outlined as below:

General objectives:

To reveal the aquaculture management practice and health status of aquaculture stakeholders and workers in Penang.

Specific Objectives:

1) To explore the current aquaculture production and management practices in Penang.
2) To identify the intention to adopt aquaculture technology and identify the barriers preventing its adoption among aquaculture stakeholders.
3) To correlate the association between health complaints, mental health status, and quality of life (QoL) among aquaculture workers.

1.5 Research Hypothesis

1) The trend of progressive development of aquaculture sector is very important in sustaining aquaculture farming activities, in terms of fish production, sales and access to extension and advisory service.
2) There is intention for adoption of aquaculture technology and barriers exist for the adoption.
3) The status of physical health, mental health and QoL of aquaculture workers are satisfactory.

1.6 Significance of Study

Aquaculture sector has contributed high value income to the country through the local trade and foreign exchange. Hence, this industry has the potential to achieve the Malaysia government's objective of increasing national aquaculture production and leverage the development. This research is fundamental to inform the aquaculture stakeholders and policymakers about the importance of ongoing planning and strategies to this economically significant sector. The study reported the fish production trends, access to extension and advisory services and aquaculture management practice in Penang. Furthermore, this study also evaluated the health complaints, mental health status and QoL of aquaculture workers.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The second chapter provides an overview of Malaysia's aquaculture industry. The review will begin with looking into the current aquaculture trends in Malaysia, particularly in Penang. This section discusses the cultured species, cultivation systems, aquaculture's socioeconomic contribution and aquaculture management practice. Following that, environmental hazards and health risks associated with fish farming are discussed.

2.2 Aquaculture Operational Definition

The operational definition of key elements is an important aspect of any research study. This section will provide insight, clarity, and standardization of key research terms and concepts for this research (Table 2.1).

Table 2.1 Aquaculture Operational Definition

Term	Definition	References
Aquaculture	The farming of aquatic organisms like fish, mollusks, crustaceans, and plants is known as aquaculture. Farming typically involves some sort of intervention to boost output, such as routine stocking, feeding, and predator protection.	Troell et al., 2004
Freshwater aquaculture	Freshwater aquaculture is the term used to describe the raising and breeding of aquatic organisms (fish, prawns, crab, shellfish, etc.) and plants for commercial purposes using ponds, reservoirs, lakes, rivers, and other inland waterways.	Li & Liu ,2019
Brackish water aquaculture	Brackish water is defined as having a salinity between freshwater and seawater and is typically found in areas where the two waters mix. The most well-known example of brackish water is the estuary, or the region where a river meets the sea.	Rich & Maier, 2015
Food security	Food security is the state in which everyone, at all times, has physical, social, and economic access to an adequate supply of food that is safe, nutritious, and meets their dietary needs.	Fanzo, 2015

Effluent	Wastewater treatment, or effluent management, is the technology and process used to remove the majority of contaminants present in wastewater in order to protect the environment and public health.	Bani, 2011
Water quality	The water quality is made up of all the physical, chemical, and biological components that have an impact on how well water is used. When it comes to fish culture, any characteristic of water that affects a fish's capacity for survival, reproduction, growth, production, or management in any way is referred to as a water quality parameter. It refers to any aspect of water resource management that focuses on improving, preserving, or restoring the quality of the water.	Boyd & Pillai, 2005
Biosecurity measures	Biosecurity measure (BSM) is the application of a segregation, hygiene, or management procedure (excluding medically effective feed additives and preventive/curative treatment of animals) that specifically aims at lowering the likelihood of the introduction, establishment, survival, or spread of any potential pathogen to, within, or from a farm, operation, or geographical area.	Huber et al., 2022
Environmental hazard	An environmental hazard is a substance, condition, or circumstance that has the potential to endanger the natural environment nearby and/or negatively impact human health.	Iderawumi et al., 2019
Health risk	The definition of "health risk" is anything that could be harmful to people's health.	Dovjak et al., 2019
Lakes	A lake is a closed body of water (typically freshwater) that is completely encircled by land and has no direct access to the sea.	Bhateria & Abdullah, 2015
Waterways	A waterway is a path or channel made of water. At this time, the length or channel means navigable, and it is a navigable body in general. Thus, canals, rivers, and canyons are included in the channel, and water bodies include lakes, straits, and oceans.	Lee, 2023
Coastline	A coastal zone is the area where land meets water.	Crossland et al., 2005
Semi-intensive	In semi-intensive systems, farmed organisms rely on intentional fertilisation to produce natural food in situ and/or on the addition of supplementary feed to supplement high-protein natural food.	Edwards, 2013
Intensive	In intensive systems, fish are fed nutritionally complete feed with little to no contribution from natural food.	Edwards, 2013
Extensive	Large-scale farming relies on natural food produced within the system rather than nutritional inputs provided by humans. Plankton is a type of natural food that includes bacterioplankton, phytoplankton, and zooplankton. It is typically high in protein (50-70%	Edwards, 2013

	dry matter) and suspended in the water column and benthos (such as insect larvae and adults, snails, and worms) in sediments.	
Closed water exchange	Closed systems can be both natural and highly engineered, such as static outdoor ponds.	Browdy et al., 2001
Recirculating aquaculture system	Recirculating aquaculture system is a technology where water is recycled and reused after mechanical and biological filtration and removal of suspended matter and metabolites	Ekawati et al., 2021
Good aquaculture practice	Good aquaculture practise is a set of considerations, procedures, and protocols that are intended to promote efficient and responsible aquaculture production and expansion while also assisting in the assurance of final product quality.	Schwarz et al., 2019
Sludge	Sludge is defined as any solid, semisolid, or liquid waste generated by a municipal, commercial, or industrial wastewater treatment plant, water supply treatment plant, or air pollution control facility, excluding wastewater treatment plant treated effluent.	Cieślik et al., 2015
Eutrophication	Excess nitrogen (N) and phosphorus (P) can cause eutrophication in water due to reactive N and P enrichment for excessive algal and other aquatic plant growth.	Liu et al., 2019
Bioremediation	Bioremediation is a biological mechanism for recycling wastes into a form that other organisms can use and reuse.	Abatenh et al., 2017
Phytoremediation	The use of green plants to clean up polluted soil and water resources is known as phytoremediation.	Vasavi et al., 2010
Wastewater treatment	Aquaculture wastewater treatment to protect receiving waters from eutrophication and to allow for possible reuse of treated water.	Lin et al., 2002
Antibiotics	Antibiotics are antibacterial compounds that are used to treat and prevent bacterial infections.	Banin et al., 2017
Vaccination	Vaccines are biological agents that stimulate the immune system to respond to a specific antigen derived from an infectious disease-causing pathogen.	Czochor & Turchick, 2014
Ergonomic	Ergonomic is the study of matching job requirements and environment to the worker to maximize efficiency, quality, and quantity of work while minimizing work-related musculoskeletal disorder.	Keyserling et al., 2008
Breeding	Breeding systems refer to the various methods of evaluating and selecting desired genetic traits in a breed or species.	Brown, 1978
Sediments	Sediment is the end result of particles in the water column beneath the sea and near the seafloor from uneaten feed. High concentrations of organic and inorganic substances.	Lastauskienė et al., 2021

2.3 Worldwide Aquaculture Practice

Fish provides over 20% of the average per capita animal protein consumption to 3.3 billion individuals worldwide, accounted for more than 17% of total animal protein and 7% of all protein consumed globally in 2017 (FAO, 2020). Over the last 50 years, global fish and seafood production has quadrupled. Not only the world's population increased by more than half a century, but the average individual now consumes about twice as much seafood as they did half a century ago (Ritchie & Roser, 2021). However, a one third of the world's fish stocks have been depleted due to overfishing of wild stock species, which are continually under pressure with growing demand for seafood (Sumaila & Tai, 2020). As a consequence, since the beginning of the twentieth century, aquaculture has grown rapidly around the world, in parallel to the increased awareness of the negative impacts of intensive fishing, such as the wild fish stocks raised an ecological concern (Rocha et al., 2022).

Global aquaculture production has more than tripled in live-weight volume from 34 MT in 1997 to 112 MT in 2017. Seaweeds, carps, bivalves, tilapia and catfish were the primary species categories that contributed to the top 75% of aquaculture production in 2017 (Naylor et al., 2021). This sector is the fastest growing food producing sector in the world, and by 2030 it is expected to contribute up to 62% for human consumption in order to meet the consumer demand (Massa et al., 2017). Global aquaculture output of food fish has increased dramatically over the previous 20 years, from 32 MT in 2000 to 82 MT in 2018, accounting for 46% of overall fisheries production and overtaking capture fisheries production by over 18 million MT (Tacon, 2020). Asia has emerged as a major producer of fish and seafood in the world, as well as a center of aquaculture growth, accounting for 92% of the live-weight volume of animals and seaweeds in 2017 (FAO, 2019). Asia has been dominating in the world by contributing 87.9% in 2018, with China leading and produced 63.7 MT of aquaculture produce annually (FAO, 2019).

2.4 Aquaculture Sector in Malaysia

Malaysia is a federation of thirteen states and three federal territories located in the Southeast Asia's central region, with the South China Sea dividing the country into two parts: the West Malaysia and East Malaysia. The land area in Malaysia covers 329,847 square kilometres, with water, such as lakes, ponds and other freshwater waterways, cover 1,200 square kilometres or 0.37 % of Malaysia's total land area. Malaysia has a 4,809 km long coastline, with Peninsular Malaysia's around 2,031 km long, while Sabah and Sarawak (East Malaysia) have a 2,778 km long coastline (Lee et al., 2020). Compared to other countries, Malaysia has an advantage in developing aquaculture because it is surrounded by the sea geographically, and has natural resources such as ponds, rivers, lakes, estuaries and coastal areas (Banu & Christianus, 2016).

Current trend of aquaculture production in Malaysia is shown in Figure 2.1, as attained by DoF Malaysia in 2021. By referring to the Ministry of Agriculture (MOA) Aquaculture Blueprint in the Eleventh Malaysia Plan (2016-2020), the fisheries industry comprising capture fisheries and aquaculture aims to achieve production of up to 48% for aquaculture production, and 52 % for capture fisheries, by 2020. A total of 77.6 % was contributed by capture fisheries, while aquaculture production accounted for 22.4 % in 2020. This finding was supported by Waiho et al. (2020), where aquaculture represents about 20 % of the total seafood production in Malaysia. The low-level of aquaculture production could be attributed to different challenges fish farmers may be facing in managing their farm (Iliyasu et al., 2016). Among this, increasing production costs, a scarcity of skilled labour, disease threats, food safety and quality of aquaculture produce have become obstacles to aquaculture development (FAO, 2022).

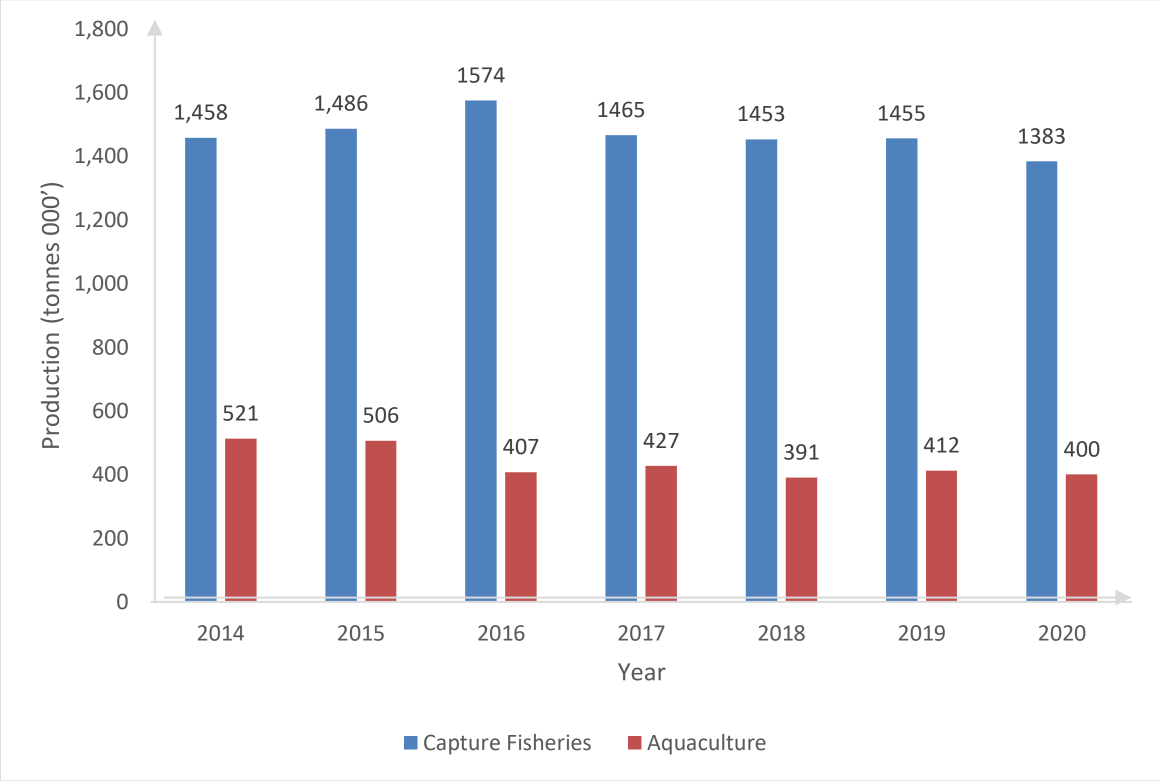

Figure 2.1: Capture Fisheries and Aquaculture Production in Malaysia from 2014-2020 (DoF, 2021)

Over the last few years, Malaysia aquaculture industry has become relatively unstable (Figure 2.2). Aquaculture productivity had been decreasing since 2014, falling from 506,276 MT in 2015 to 407,387 MT in the following year, and eventually reaching the lowest production of about 391,465 MT in 2018. The aquaculture industry grew in 2019, with a total production of 411,782 MT, reflecting a 5.19% rise in production volume over 2018. However, aquaculture production has experienced a slight decline in 2020 with production of 400,017 MT. The unstable scenario of aquaculture industry in Malaysia may be caused by several issue and challenges, such as the high cost of production as impacted by limited resources and supply of inputs (Samah, 2020).

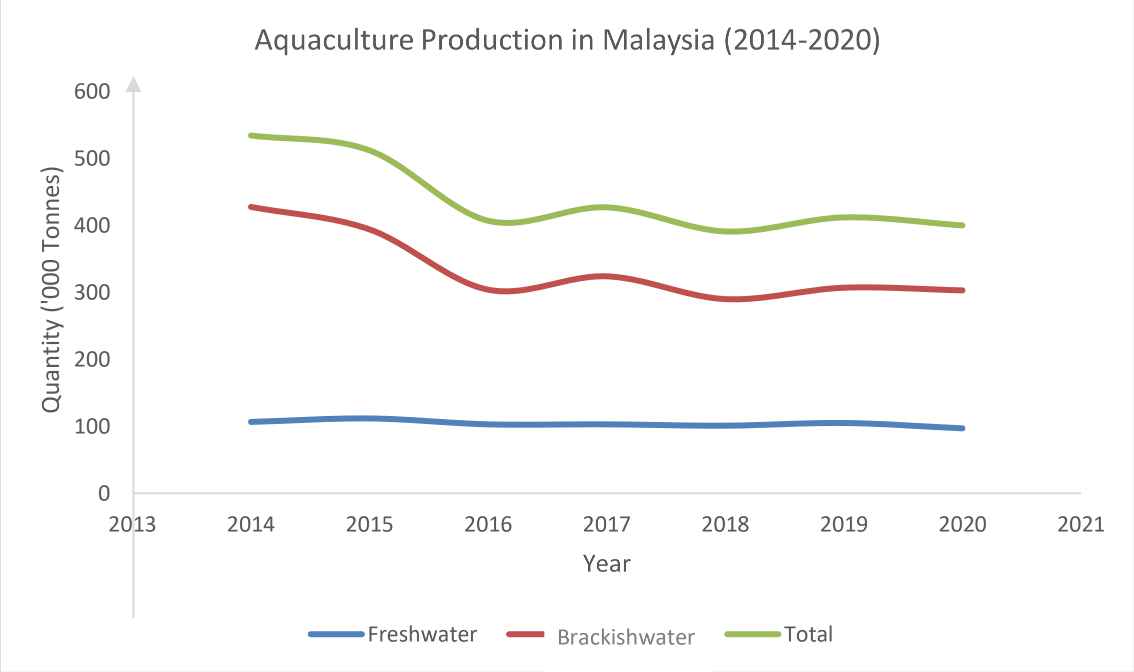

Figure 2.2: Aquaculture Production in Malaysia (2014-2020) (DoF, 2021)

Among the states in Malaysia, Sabah was the largest contributor to the total aquaculture production, as well as the overall brackish water production in Malaysia (Table 2.2). In 2020, Sabah alone contributed nearly 182,061 MT of brackish water aquatic plants, particularly seaweeds and accounting for almost all of the seaweed production throughout Malaysia, and nearly 60.1% of total brackish water aquaculture production (DoF, 2021).

Table 2.2: Aquaculture Production by State and Wholesale Value in 2020 (DoF, 2021)

State	Production (Tonnes)			Wholesale Value (RM '000)		
	Freshwater	Brackish water	Total	Freshwater	Brackish water	Total
Perlis	143	440	584	948	6,675	7,624
Kedah	3,442	8,503	11,945	20,699	130,531	151,229
Pulau Pinang	2,712	34,318	37,030	12,139.90	629,566	641,706
Perak	32,712	32,480	65,192	185,490	485,798	671,288
Selangor	15,825	4,877	20,702	149,333	129,220	278,553
Negeri Sembilan	3,368	784	4,153	30,963	19,113	50,076
Melaka	3,236	452	3,689	13,601	13,611	27,212
Johor	6,393	13,363	19,755	41,447	326,710	368,157
Pahang	10,971	4,243	15,214	137,129	108,439	245,568
Terengganu	2,298	2,826	5,124	23,565	59,792	83,357
Kelantan	4,771	1,251	6,022	27,354	22,067	49,421
Sarawak	9,479	6,700	16,179	97,089	132,561	229,650
Sabah	1,857	192,569	194,426	26,661	284,181	310,842
W.P. Labuan	0.61	0.1	0.71	21	3	24
W.P Kuala Lumpur	1.7	-	1.7	26	-	26
Total	97,210	302,807	400,016	766,465	2,348,267	3,114,732

The red seaweeds, *Kappaphycus alvarezii* and *Kappaphycus striatum*, were the most widely farmed seaweeds in Malaysia (Nor et al., 2020). Seaweeds are greatly valued for their carrageenan content, which is extracted after the sun drying process. Carrageenan is a substance that is widely used in the food, pharmaceutical and cosmetic industries. In Sabah, seaweed farming is a family and community-based economic activity. Semporna, Tawau, Kunak and Lahad Datu are the main district areas for the cultivation of seaweed (Eranza et al., 2017). Due to the enormous output of seaweed carrageenan from Sabah, Malaysia was ranked as one of the top five global producers of seaweed carrageenan, alongside Indonesia, the Philippines, the United Republic of Tanzania and Vietnam (FAO, 2018).

2.5 Aquaculture Cultivation Species

In Malaysia, the aquaculture production in 2020 recorded 400,017 MT with a wholesale value of RM 3,114,731. Freshwater aquaculture contributed 22.7% of total aquaculture production, with a wholesale value of 766,462 million. Meanwhile, the brackish water cultivation system contributed about 77.3 % of total aquaculture production, valued at 2,347,245 million in 2020 (DoF, 2021).

2.5.1 Freshwater Species

Freshwater species is commonly known as a species that are found in inland rivers, streams, lakes and areas of weak brackish water (Keat-Chuan et al., 2023). Freshwater fish has been found to be a viable resource and has potential to grow in Malaysia market due to the abundance of natural resources and uprising demand (Iliyasu et al., 2016). Furthermore, breeding freshwater species is a profitable activity because the freshwater fish-rearing industry is growing among the agriculturists and fishermen (Mustafa et al., 2018). The capability to breed and farm freshwater fish at a low cost using simple technologies makes them available to low- and middle-income consumer (Belton et al., 2020). Freshwater fish, such as the tilapia or catfish, have an advantage in terms of disease resistance, as well as the ability to tolerate poor environmental conditions, such as low water quality and high stocking density (Samah & Kamaruddin, 2015). The main cultured species for freshwater aquaculture in Malaysia were freshwater catfish (*Clarias sp.*), black and red tilapia (*Oreochromis sp.*), riverine catfish (*Pangasius sp.*) and giant freshwater prawn (*Macrobrachium rosenbergii*) (Yusoff, 2015).

2.5.1(a) Tilapias

Tilapia fish is the member of the Cichlidae family, which originated from the African continent. There are at least 900 known species and an estimated more than 1300 species worldwide as of today (Khatib & Jais, 2021). Tilapia is a hardy fish that is ideal for breeding due to its short cultural period of about 6 months. In addition, it tolerates high stock densities well, has a high productivity rate, and can be widely adapted to a variety of cultural systems (Mohamad et al., 2021). Among freshwater species, the red hybrid tilapia (*Oreochromis spp.)* collectively contributed to about 28.8 % of the total freshwater aquaculture production in Malaysia in 2020 (Table 2.3). Red tilapia, also known as red hybrid tilapia, is not a true tilapia species, but is produced through continuous selective breeding from shortlisted tilapia species of the genus Oreochromis that have an appealing red coloration (Mohamad et al., 2021). According to Gupta and Acosta (2004), red tilapia is a hybrid fish species produced by interspecific crossing of albino Mozambique tilapia (*O. mossambicus*) and Nile tilapia (*O. niloticus*). Aside from red tilapia, black tilapia was also widely cultured in the freshwater aquaculture industry, accounted 3.5% of overall freshwater production in 2020. However, red tilapia is favoured over black Nile tilapia in most conditions because of its red colour resemblance to premium marine species such as the red snapper (*Lutjanus campechanus*) and sea bream (*Chrysophrys major*) (Gupta & Acosta, 2004; Towers, 2005; Mohamad et al., 2021).

Table 2.3: Aquaculture Production and Value from Freshwater Culture System by Species in 2020 (DoF, 2021)

Fish Species	Production (tonnes)	Value (RM thousand)
Red tilapia *Tilapia Merah*	28,009	299,822
Freshwater catfish *Keli*	29,012	129,661
River catfish *Patin*	18,227	132,456
Labeo Rohita *Rohu*	5,198	24,854
Black tilapia *Tilapia Hitam*	3,453	28,937
Bighead carp *Kap Kepala Besar*	2,228	10,312
River carp *Lampam Sungai*	22	35,652
Common carp *Lee Koh*	1,110	7,062
Javanese carp *Lampam Jawa*	1,147	9,764
Grass carp *Kap Rumput*	414	3,596
Giant freshwater prawn *Udang Galah*	192	12,926
Snakehead *Haruan*	30	397
Giant snakehead *Toman*	136	1,772
Others	8,013	69,251
Total	97,209	766,462.45

2.5.1(b) Catfish

Catfish is classified under the order Siluriformes, which includes over 3000 species from 36 families. Catfish was the most abundant freshwater species, and ranked fifth in the world in terms of fresh and brackish water fish culture, with an annual production of around 350,000 tonnes (Khatib & Jais, 2021). Because of their hardiness, high fertility, rapid growth rate, and ease of culture characteristics, this species became popular among fish farmers (Bagarinao & Flores, 1995; Saba et al., 2020). This species, with an omnivorous feeding habit, is extremely resistant to environmental stress and disease (Anati et al., 2021). In Malaysia, freshwater catfish is the largest freshwater species cultured, accounting for approximately 29.8% of total freshwater production (Table 2.3).

The three most widely farmed catfishes in the aquaculture industry include *Clarias spp*., *Pangasius spp*. and *Mystus numerus* (Mahmud et al., 2019). Meanwhile, of the catfishes, *Clarias spp*. was the most commonly farmed, with the walking catfish (*C. batrachus*), bighead catfish (*C. macrocephalus*) and African catfish (*C. gariepinus*) being the most prevalent species. *C. batrachus* is the most widely cultivated species, especially in Thailand. It grows quickly and easily, but the meat is not particularly tender. On the other hand, *C. macrocephalus* is preferred for its superior flavour and tender meat, but its cultivation is limited due to the slow growth and scarcity of seed (Khatib & Jais, 2021). *C. gariepinus*, or commonly known as african catfish, gives significant impact on aquaculture industry, and have grown more rapidly in the last two decades surpassing red tilapia in 2008, making catfish the most abundant fish species and highly produced (Anati et al., 2021; Khatib & Jais, 2021). Furthermore, *Pangasius spp.,* including the silver catfish (*P. micronemus* and *P. nasutus*) and striped catfish (*P. hypophthalmus*), all of which were farmed extensively in Peninsular Malaysia, especially in the rivers of Pahang (Hashim et al., 2015; Mahmud et al., 2019). In Malaysia, *Pangasius spp*. can be found in most of the water streams such as the Pahang River, Kenyir Lake and Kelantan River (Mustafa et al., 2018).

2.5.1(c) Carps

The common carp (*Cyprinus carpio*) is a member of the order Cypriniformes and the family Cyprinidae, the largest freshwater fish family (Rahman, 2015). Major freshwater carp species reared in Malaysia including javanese carp (*Puntius gonionotus*), common carp (*Cyprinus carpio*), big head carp (*Ctenopharyngodon idella*), marble goby (*Oxyleotrix marmoratus*) and one of the Indian major carp species, rohu (*Labeo rohita*) (Babji et al., 2015). As shown in Table 2.3, rohu contributed the highest production volume of any carp species to total freshwater aquaculture production in 2020, accounting for approximately 5,198 MT and worth RM 24.9 million. Due to its high growth potential and compatibility with other freshwater carps in polyculture, rohu has become one of the most popular species cultured in Malaysia (Majumder et al., 2018). Rohu is a tasty, cost-effective fish for local consumers, and it has a high market value (Ahasan et al., 2020). In addition, the skin of rohu was covered with thick scale, making it a great alternative source of gelatin to replace both porcine and bovine gelatine (Das et al., 2017).

2.5.1(d) Crustaceans

The giant freshwater prawn (*Macrobrachium rosenbergii*) is a major crustacean species produced in inland aquaculture in many tropical and subtropical countries around the world (Thanh et al., 2009). This species was the dominant species amounting approximately 192 MT production volume (Table 2.2). *M. rosenbergii*, a giant freshwater prawn, is one of the commercial scale aquaculture species given major focus as food and food products for consumption and export (Banu & Christianus, 2016). Furthermore, rearing this species plays an important role in Malaysia's economic development with the target to increase the economic activities of the surrounding communities, providing a source of income for local prawn farmers, and alleviating poverty. However, Firuza et al. (2020) discovered that the farming of *M. rosenbergii* had been constantly impacted by water contamination as a result of increased human activities and contaminants discharge into the water stream supplying the prawn farms.

2.5.2 Brackish water species

Brackish water is a wide terminology used to define water with salinity between freshwater and seawater, and it is often found in transition zones where the two waters mix. The most well-known example of brackish water is the estuary, which is the part where the river meets the sea (Rich & Maier, 2015). Brackish water aquaculture industry has becoming driving force in raising the socioeconomic level of the community. The main cultured species for brackish-water species were Tiger shrimp (*Penaeus monodon*) and Whiteleg shrimp (*Penaeus vannamei*), cockles (*Tegillarca granosa*), grouper (*Ephinephelus fuscoguttatus*), red snapper (*Lutjanus argentimaculatus*) and seabass (*Lates calcarifer*). In practice, fin fish (sea bass, grouper and snapper), crustaceans (black, white tiger prawn shrimp), bivalves (clams, mussels and oysters) and seaweeds are the most commonly cultured marine aquaculture species in Malaysia (Lee & Liew, 2016).