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Review

A Systematic Review on Adaptation Practices in Aquaculture towards Climate Change Impacts

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Abstract: The impact of climate change is one of the many challenges faced by aquaculture communities nowadays. Only a limited number of articles have attempted to systematically review available literature in this field, which has led to the current study, aiming to develop a systematic review related to the practice of adapting to climate change among aquaculture communities. This systematic review was guided by the PRISMA Statement (Preferred Reporting Items for Systematic reviews and Meta-Analyses) in its systematic searching strategy on Scopus, Web of Science, and Google Scholar, resulting in the selection of 20 related studies. All selected articles were assessed using the Mixed Method Appraisal Tool (MMAT). Employing thematic analysis, five main themes resulted, namely Governmental (five subthemes), Community (three subthemes), Facilities (five subthemes), Temperature (two subthemes) and Financial (three subthemes), along with 18 subthemes. Based on the pattern of previous studies, the review presented several recommendations for scholars, agencies, and communities to consider in future.

Keywords: systematic review; aquaculture; entrepreneur; climate change; adaptation practice

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1. Introduction

The aquaculture industry provides half of global seafood production at present and is one of the fastest-growing food production sectors globally [1]. According to the report by [2], the aquaculture industry has contributed significantly to world fish production, totalling 46.0% of the sector in 2016–2018, up from 25.7% in 2000. Aquaculture businesses across the globe had the highest harvest productivity among seafood producers in 2018 (114.5 million tonnes in live weight), with a total farm gate sale value of more than USD 250 billion [2].

However, similarly to other industries, aquaculture production is affected by climate change, which affects its contribution to the global food supply [3]. Scholars have touched upon some of the impacts climate change may have on aquaculture [4], for example, projected that rising sea levels and extreme weather (e.g., heavy and unstable rain patterns) would trigger the risk of flooding, which is one of the biggest threats to a local aquaculture community (AC). The authors of [5], meanwhile, noted that temperature changes in both air and water are exposing the many reared species to different stresses and physiological effects which later affect their growth and development. This also increases their susceptibility to diseases and infections. Hence, ACs are among the most vulnerable groups to climate change, since their yields might be reduced, their physical infrastructure destroyed and their vulnerability to extreme weather impacts increased [6,7]. An AC comprises anyone who is involved in aquaculture activities, such as entrepreneurs, family members who assist them and those who are involved in selling or marketing aquaculture products.

Understandably, to reduce the risks and losses associated with these impacts, scholars have agreed that adaptation is the best remedy [8–13]. In this context, adaptation towards climate change can be defined as a situation where individuals, families or communities are able to adjust to external conditions until an optimal or maximum fit is achieved [14].

The Need for a Systematic Literature Review Related to Adaptation Practices among Aquaculture Communities

As the impacts of climate change are forecast to worsen in future, scholars have attempted to understand how communities are responding to these challenges. As one of the groups significantly affected by climate threats, ACs have practised several methods to adapt to these changes, as reported by several researchers such as [7,15–17]. Although related articles are abundant, very few have attempted to review these articles systematically, which has reduced the ability of future scholars to identify changes and new opportunities in the emerging literature. In addition, as there is a need to provide current knowledge to ensure that significant insights can be derived from the existing literature, the current study aims to conduct a systematic literature review on adaptation towards climate change impacts among ACs.

In the context of this study, a systematic review can be interpreted as an examination of a formulated question that uses systematic and explicit methods to identify, select and critically appraise relevant research studies, and analyse their data [18–20]. Conducting a systematic review of this issue is important since there is a growing global discourse concerning it. The method implemented in this review allows for the identification of gaps and determines the direction for future research related to how ACs are responding to the impacts of climate change [18,20,21]. Furthermore, a systematic review enables researchers to identify patterns in previous studies and assists them in understanding related issues that can provide insights into effectively counteracting the negative impacts of climate change.

2. Materials and Methods

This section starts with the authors' explanation of the publication standard used, namely Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA); subsequently, the authors explain the formulation of the research questions, the systematic searching strategies practised (identification, screening, eligibility), the quality appraisal, data extraction and analysis.

2.1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)

PRISMA is the publication standard that guided this systematic review. PRISMA guides researchers to formulate research questions that permit systematic research, identify inclusion and exclusion criteria and attempt to examine the large database of scientific literature over a defined period [22]. In this case, PRISMA guided the researchers to perform rigorous searches on terms related to aquaculture entrepreneurs' responses to climate change and its impacts, and then code for information in future environmental management reviews.

2.2. Formulation of Research Questions

In the initial phase of the review, the study needs to develop a suitable research question, which guides the entire systematic review methodology. As the main objective of this article was to systematically review the existing literature related to climate change adaptation among AC, the following research question was selected—what adaptation practices have been used by AC in facing climate change? Having established the research question, the main focus of this article was placed on the adaptation practices employed by AC rather than a hard-science-related perspective on climate change. Special attention was given to AC as this group is one of the groups that contributed to the 11.6 million tonnes of production by the world's inland waters fisheries in 2016, representing 12.8% of total marine and inland catches [3].

2.3. Systematic Searching Strategy

Our searching strategy consisted of three subprocesses, namely identification, screening, and eligibility.

2.3.1. Identification

Identification is a process used to enrich the main keywords used. This is important as the identification process increases the possibility of obtaining more related articles for the review [23]. To enrich the keywords, the researchers focused their efforts on searching for any related terms and synonyms for the main keywords used (i.e., aquaculture, adaptation, climate change and entrepreneur were used) using an online thesaurus, referring to keywords used by past studies, keywords suggested by databases and by asking the opinions of experts. The enriched keywords were then combined using search functions such as Boolean operators, phrase searching, truncation, wild cards, and field code function, as seen in Table 1.

Three selected databases were used in the searching process, namely Scopus, Web of Science and Google Scholar. The searching process was performed in February 2020. The researchers developed a full search string to search for related articles in Scopus and Web of Science (see Table 1). In Google Scholar, the researchers searched for any related articles using the same keywords used in Scopus and Web of Science, and whenever appropriate, searching techniques such as Boolean operators, phrase searching and field code functions (either combining these search techniques or using them separately) relying upon the searching efforts. Furthermore, the authors performed manual searching—handpicking relevant articles from Scopus and Google Scholar. In this process, a total of 36 potential articles were identified, and later, two duplicated articles were excluded, meaning that 34 articles were then included in the study.

Table 1. The Search String Used for the Systematic Review Process.

Databases	Keywords Used
SCOPUS	TITLE-ABS-KEY ((“climate* chang*” OR “climate* risk*” OR “climate* variabilit*” OR “climate* extreme*” OR “climat* uncertaint*” OR “global warming*” OR “temperature rise*” OR “sea level rise*” OR “el-nino” OR “la-nina” OR “el nino” OR “la nina”) AND (“adapt* abilit*” OR “adapt* strateg*” OR “adapt* capacit*” OR “adapt* capabilit*” OR “adapt* strength*” OR “adapt* potential*” OR “adopt* abilit*” OR “adopt* strateg*” OR “adopt* capacity*” OR “adopt* capabilit*” OR “adopt* strength” OR “adopt* potential*”) AND (“aquacultur*” OR “hydroponic* cultur*” OR “hydro* ponic* aquacultur*” OR “tray* agricultur*”) AND (“entrepreneur*” OR “contractor*” OR “producer*” OR “business person*” OR “impresario*” OR “industrialist*”))
WEB OF SCIENCE	TS = ((“climate* chang*” OR “climate* risk*” OR “climate* variabilit*” OR “climate* extreme*” OR “climat* uncertaint*” OR “global warming*” OR “temperature rise*” OR “sea level rise*” OR “el-nino” OR “la-nina” OR “el nino” OR “la nina”) AND (“adapt* abilit*” OR “adapt* strateg*” OR “adapt* capacit*” OR “adapt* capabilit*” OR “adapt* strength*” OR “adapt* potential*” OR “adopt* abilit*” OR “adopt* strateg*” OR “adopt* capacity*” OR “adopt* capabilit*” OR “adopt* strength” OR “adopt* potential*”) AND (“aquacultur*” OR “hydroponic* cultur*” OR “hydro* ponic* aquacultur*” OR “tray* agricultur*”) AND (“entrepreneur*” OR “contractor*” OR “producer*” OR “business person*” OR “impresario*” OR “industrialist*”))

2.3.2. Screening

The researchers then executed the screening process on the 34 articles selected via the identification process. The criteria selected for the screening process consisted of the literature type, language, and year of publication (Table 2). Journal article were chosen as the primary type of literature for this review since they offer primary data, which are vital for a systematic review study. Articles in English were mainly referred to since it would ease the authors' comprehension and understanding of the content of the articles. As the authors wished to examine the pattern of evolution of the research on this topic, the review was based on the concept of study maturity, which emphasizes that the number of articles must be adequate to perform a systematic literature review [24,25]. The study selected a time period of eight years (i.e., articles published between 2013 and 2020), since this timeline provided a good number of articles to be considered in the review. Later in this process, one article was removed as it was published in Portuguese rather than English.

Table 2. The Inclusion and Exclusion Criteria.

Criterion	Eligibility	Exclusion
Literature type	Journal (research articles)	Journals (systematic review), book series, book, chapter in book, conference proceeding
Language	English	Non-English
Timeline	Between 2013 and 2020	2012 and earlier

2.3.3. Eligibility

The third phase of the systematic review process in this study was related to eligibility. It was the second process of screening to determine that all remaining articles from the screening process were in line with the criteria. In this process, the articles were once again checked for suitability for the review, based on title and abstract. If the authors were still unsure of the contents, they then opted to examine the contents of the selected articles. After careful examination, a total of 13 articles were excluded due to the article being irretrievable from database, published before 2013 or not focusing on adaptation practices that been used by aquaculture entrepreneurs to face climate change. The remaining 20 articles were then ready for appraisal for quality (see Figure 1).

2.4. Appraisal of Quality

As the review relied on mixed research designs (quantitative + qualitative + mixed methods), the selected articles were appraised in terms of quality using Mixed Method Appraisal Tool (MMAT) version 2018 [26]. Two reviewers were assigned to assess the quality of the selected articles based on the article's clarity surrounding the research questions, confidence in the assessment of the research question, sampling, methods of collecting data, and suitability of the statistical analysis performed to achieve the objective. In addition, the reviewers also looked into how data in the articles were interpreted, presentation of results, discussion, and conclusion. The quality was determined based on the MMAT guidelines, with 25% accounting for low-quality articles, 50% as average, 75% being above average, and 100% being high. The reviewers then categorized 14 articles as having high average quality while the remaining six were above average.

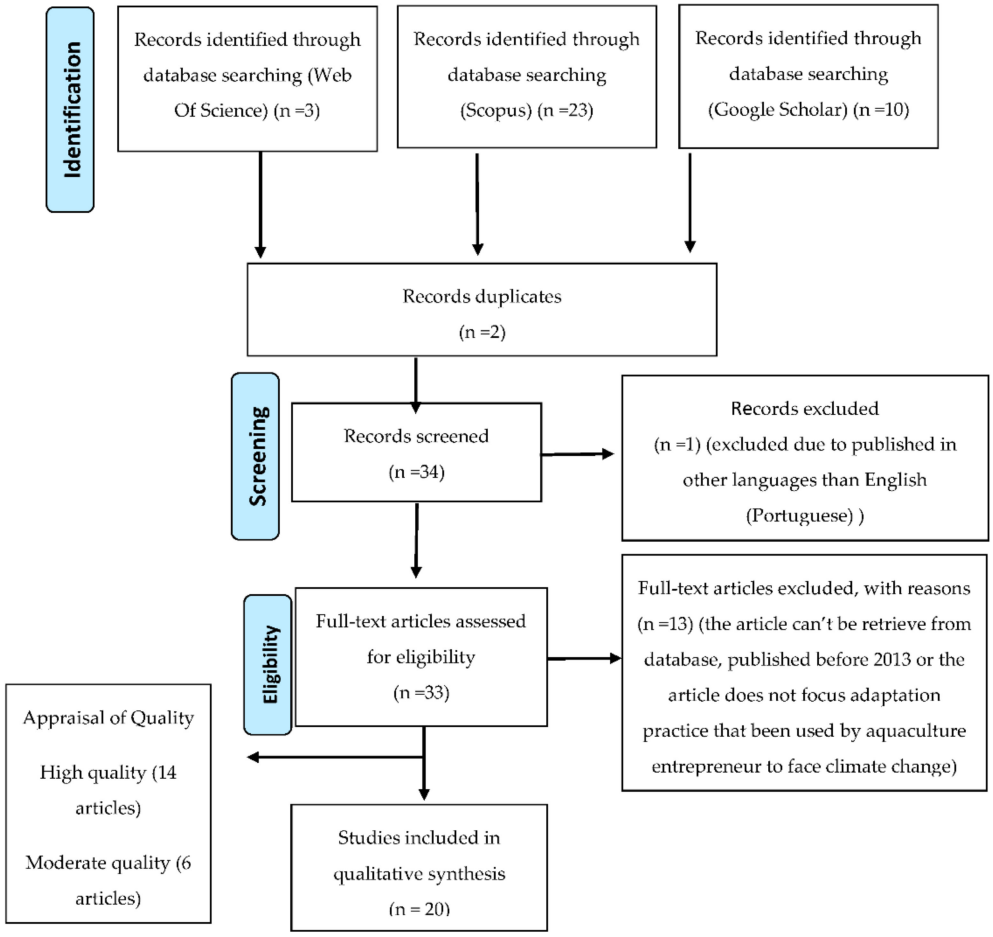

Figure 1. The flow diagram of the study adapted from [27].

2.5. Data Extraction and Analysis

The remaining articles were assessed and analysed. Before analysis, the authors needed to extract all relevant data from the selected articles in which the study's research question guided the process. As the review focused on the primary and empirical data of the selected previous studies, the authors first sought out the relevant three sections in these articles, namely the abstract, results and discussion, before proceeding to the other sections to look for any related information All of the extracted data were placed into a table to ease the synthesis process. A qualitative synthesis was then performed using thematic analysis to identify themes related to climate change adaptation among AC. Thematic analysis is an analysis technique used to identify, analyse, organise, describe and report themes recognised within the extracted data [28]. Thematic analysis offers several advantages for researchers. First, it examines different perspectives, detecting similarities and differences while at the same time generating unanticipated insights. The technique assists in summarising the main theme of large data, urging researchers to utilise a well-structured method to handle the data, which then results in clear and organised findings [29]. More importantly, thematic analysis is better suited the nature of this present review, which focused on mixed research designs [30].

In generating themes, patterns had to be identified based on the extracted data. The researchers developed themes by noting any similarities or relationships between the extracted data. Two coders performed the process, which generated a total of five main themes, namely Governmental, Community, Facilities, Temperature and Financial. In each of the developed themes, the authors then conducted a thematic analysis to detect any suitable subthemes, which resulted in a total of 18 subthemes. The accuracy of the main themes and subthemes were re-examined by the coders to ensure its accuracy and

suitability to the study's research questions. Any disagreement on the developed themes or subthemes between the coders was discussed, and external expert opinions were sought if the coders failed to reach a mutual agreement. The experts would then provide the final decision on the subtheme most appropriate for this study. During this process, several subthemes were re-located within the six main themes and re-named. Eventually, the authors identified five main themes and 18 subthemes.

3. Results

The review resulted in the identification of five main themes and 18 subthemes related to adaptation practice used by AC in facing the challenges presented by climate change. The five main themes, as mentioned previously, were Governmental (five subthemes), Community (three subthemes), Facilities (five subthemes), Temperature (two subthemes) and Financial (three subthemes). The results can be seen in Tables 3 and 4. The results provide a comprehensive analysis of the current adaptations practised by the AC in facing climate change.

3.1. General Background of The Selected Studies

Regarding the selected studies, two studies focused on AC in Norway regarding climate change adaptation practice [15,31], two studies focused on Malaysia [32,33], three studies focused on India [17,34,35], five studies focused on Bangladesh [6,36–39], one study focused on Peru [16], two studies focused on Vietnam [14,40], one study focused on Thailand [41], one study focused on Nepal [7], one study focused on Cambodia and Vietnam [42], one study focused on member states of the United Nations [43] and one study focused on aquaculture entrepreneur adaptation practice in facing climate change in 62 developing countries [44]. Moreover, there were four quantitative research studies, seven qualitative research studies and two mixed methods (qualitative and quantitative) studies selected for the review.

3.2. Adaptation Practices Exercised by Aquaculture Community to Face Climate Change Impacts

This section focuses on the adaptation practice exercised by AC in facing climate change, based on the five themes as mentioned earlier, namely Governmental (five subthemes), Community (four subthemes), Facilities (eight subthemes), Temperature (two subthemes) and Financial (five subthemes).

3.2.1. Governmental

Nine of the 20 studies focused on the assistance received from the government as one of the adaptation practices relied on by AC in facing the impacts attributed to climate change. This systematic review found that three studies focused on product markets (PM), five studies focused on standard policy and management (SP)—a subtheme of Governmental—two studies focused on capacity training (CT), four studies focused on associations cooperation (AC)—a subtheme of Community—and three studies focused on strengthened relationships (SR) (Table 3).

Table 3. The Themes and Subthemes.

	MAIN STUDY DESIGN	Governmental				Community				Facilities				Temperature		Financial		
AUTHOR/COUNTRIES		**PM**	**SP**	**CT**	**AC**	**SR**	**SI**	**MR**	**WP**	**CD**	**CM**	**WS**	**TM**	**NB**	**TS**	**SD**	**FA**	**GS**	**JD**
Falconer et al. (2020)—Norway	QN									✓	✓				✓	✓			
Kluger et al. (2019)—Peru	QN				✓		✓				✓	✓				✓	✓	✓	
Pelletier et al. (2014)—62 Developing Countries	QN		✓								✓								
Hamdan et al. (2015)—Malaysia	QN										✓								
Idris et al. (2013)—Malaysia	QL	✓				✓	✓	✓			✓						✓		
Mohanty (2018)—India	QL		✓	✓					✓			✓	✓	✓	✓			✓	
Islam et al. (2016)—Bangladesh	MM										✓								
Ahmed et al. (2014)—Bangladesh	QL				✓						✓								
Vormedal (2017)—Norway	QL	✓	✓		✓														
Gopal et al. (2014)—United Nations	QL								✓										
Boonstra & Hai Hanh (2015)—Vietnam	MM																		✓
Gurung et al. (2018)—Nepal	QL																		✓
Biju Kumar et al. (2017)—India	QL	✓	✓	✓		✓		✓	✓		✓	✓	✓	✓		✓			✓
Dubey et al. (2017)	MX										✓			✓					
Hossain et al. (2018)	MX								✓								✓		
Islam et al. (2019)	MX										✓								✓
Joffre et al. (2018)	QN		✓		✓														✓
Lebels et al. (2015)	MX					✓	✓				✓								✓

Table 3. *Cont.*

	MAIN STUDY DESIGN	Governmental	Community	Facilities	Temperature	Financial
Navy et al. (2017)	QN			✓⚜ ⚜✓		⚜✓
Shameem et al. (2015)	MX			⚜✓		⚜✓

QN = Quantitative QL = Qualitative MM = Mix Method; ⚜, ✓; = themes/sub-themes can be found in the study

Table 4. Themes and Subthemes—Elaboration.

GOVERNMENTAL		COMMUNITY		FACILITIES		TEMPERATURE		FINANCIAL	
PM	Products Markets	SI	Spread Risk Information	CD	Change of Diet	TS	Temperature Tolerant Strains	FA	Financial Access
SP	Standard Policy and Management	MR	Monitoring Rotation System	CM	Cage Management	SD	Seasonal Data Monitoring	GS	Government Support
CT	Capacity Training	WP	Women/family members Participation	WS	Warning System			PC	Price Control
AC	Associations Cooperation			TM	Technology Management			JD	Job Diversity
SR	Strengthened Relationship			NB	Natural Barriers				

Product Market (PM)

One of the approaches for AC in adapting to the impact of climate change is by strengthening their marketing strategy. This strategy can be called an indirect adaptation as AC expand their markets mainly for profits and not directly for adaptation purposes. It should be understood that a larger market for their harvests means a continuous supply of their aquaculture products can be sold and poor sales avoided. More importantly, a wider market provides opportunities for the entrepreneurs to generate more income, allowing them to have better reactive and proactive responses towards any negative impacts of climate change. Notably, one of the ways to strengthen their marketing strategy is through government assistance. A study in Malaysia indicated that AC had sought related agencies assistance to market their aquaculture yields. According to [33], marketing is a common issue faced by AC as they have a difficult time promoting their products. In their study, related government agencies developed an efficient and effective food and agricultural marketing chain to sustain customer value for AC; in this way, AC can focus on rearing fish.

In contrast, a governmental agency can aid in creating and sustaining markets for aquaculture entrepreneurs' products. In another study by [31], the importance of penetrating international markets was emphasised, which can be accomplished through the assistance of government agencies where the agencies ensure the aquaculture products are fulfilling certain standards, enabling them to market their products in competitive international markets. The study by [34], noted that government agencies assist AC by improving market access through eco-certification and other mechanisms. Accordingly, while this means that aquaculture outputs are not going to be certified as a product, they must gain certification as it provides a high-quality nature-based tourism experience. In this way, AC can expand their product market into the tourism industry.

Additionally, being in line with what the market wants will ensure the sustainability of the aquaculture business, allowing entrepreneurs to avoid over harvesting and enabling them to run a cost productive business [33]. Knowledge-sharing sessions and forums have been made available to AC, which assists them in finding information on current demands. Hence, important information, such as the best places that offer the best prices, and extreme weather forecasts are shared among the participants [34].

Standard Policy and Management (SP)

Standard policy and management are one of the governmental subfactors that have implications for AC. As climate change has an impact in a multitude of ways and results in diverse social and economic outcomes for AC, having standard policies and management allows the entrepreneurs to formulate a uniform and consistent adaptation in order to minimize the risks of the impacts caused by climate change. At the same time, relevant policies give them guidance in formulating climate change adaptation strategies. In this vein, refs [31,40,44] suggested that the standard polices encourage self-organisation among the aquaculture entrepreneur community, allowing adjustment to unforeseen changes or policy outcomes regarding climate change. In a separate study by [17], it was suggested that three standard policies and management disciplines can be adapted globally, namely (i) the ecosystem approach to aquaculture (EAA) as a global strategy; (ii) community-based adaptation strategies and; (iii) integrated coastal zone management. The authors of [34] shared a similar notion saying that the standards in the policy could be created by integrating climate change risk in the state's disaster management policy.

Capacity Training (CT)

The study by [17] concluded that the AC industry needs to be aware of environmental changes in order to better adapt to climate change. This is important as climate change's impacts are unpredictable and forecasted to become worse in the future. To have a better awareness on the changing climate, related government agencies have diversified the skills of AC through training and the initiation of the climate field school. Research by [34] suggested that the training should include timescale data on the status and dynamics

of coastal ecosystems so that the aquaculture community is aware of their surroundings. Consequently, the training assists the aquaculture community to predict the impact of climate change on various coastal ecosystems and assess erosion-prone areas on the coast that are related to their aquaculture farm.

Associations' Cooperation (AC)

The authors of [31,40] suggested that assistance from the representative association enabled AC to have an appropriate channel to voice their views and lobby the government for more appropriate legislation and support related to climate change adaptation. This association can be an effective mediator in voicing the needs and opinions of AC. It is important for AC to have a voice as the authorities need to avoid any climate change adaptation strategies that are contrasting to the needs, abilities and interests of the target groups. The authors of [16], highlighted the importance of the association to place pressure on the authorities as a means to expedite the support from the government and private corporations. Research by [39] found that the aquaculture community, via their association, gained access to resources and/or financial capital (income, savings and credit) that enabled them to have some degree of control in environmental (water and land), demographic (knowledge of climate risks, farming skills and health), social (community-based organisation and social support institutions), and physical (infrastructure and facilities) domains.

Strengthened Relationship (SR)

Climate change has brought challenges for the AC and they need government assistance to effectively adapt to the impacts of climate change. Government assistance in a form of finance, training and advice would be useful in aiding their adaptation efforts. The study by [34] concluded that effective public, private and NGO partnerships should be developed in the aquaculture community to broaden connections with other sectors, and concurrently, gain more support for their aquaculture businesses. Governmental agency officers, for example, have taken the initiative to spend more time with the entrepreneurs, which has strengthened their relationship in addition to allowing the government to gain first-hand information from the entrepreneurs. The research undertaken by [33,41] explained the importance of this particular subtheme, noting that good relationships between the authorities and AC act as a key for increasing the productivity of the AC.

3.2.2. Community

Seven of the 20 studies focused on the community as the adaptation practices used by AC in facing climate change. This systematic review found that three studies focused on spreading risk information (SI) as a subtheme for the community as the adaptation practice, two studies focused on the monitoring rotation system (MR), and four studies focused on women's participation (WP) (see Table 3).

Spread Risk Information (SI)

The spread of risk information (SP) is one of the subthemes under the main theme of the community. As climate change is expected to worsen in the future, any proactive adaptation strategy would minimize associated risks and threats. One of the effective ways to have a proactive strategy is by spreading the right information to the right target groups [16]. Access to information on climate change impact, is an important aspect in aquaculture rearing, as not everyone has an equivalent level of information and knowledge. The authors of [33] acknowledged the importance of spreading information relative to climate risks since the aquaculture community should be informed about diseases, methods of prevention, treatment, and the safe use of chemicals. In addition, information on the methods for detecting seed quality at earlier stages has also been disseminated, assisting other entrepreneurs in selecting only the best seeds for their cages. Due to their educational level, age and income, traditional sources of information, such as television, radio,

community broadcasts, fisheries officials and colleagues, are still the main preference of the AC for receiving information [41].

Monitoring Rotation System (MR)

Similarly, the challenges posed by the natural environment can be undesirable and unpredictable to a certain extent, and within the scope of aquaculture, the impact of flooding has raised serious concerns among entrepreneurs. This is why continuous monitoring of aquaculture farming is practiced [33]. It is important to monitor the cages, for example, by hiring people who are trusted or have a common understanding, similar to AC operator. This was achieved via a systematic and planned MR system. The study by [34] also noted that the MR system is one of the community subfactors in which the aquaculture community can become actively involved in disaster preparedness, planning and the mitigation process. Further, ref [34] added that disaster preparedness allows AC to take proactive measures and actions by observing any sign of climate change-related disaster, allowing them to strategize through proper planning and taking mitigating actions.

Women's Participation/Family Members' Participation (WP)

One of the approaches for acquiring a better adaptation practice is minimising the family's reliance on the head (or leader) of the family as a sole financial source. This can be achieved by involving more women (wives and children) in aquaculture activities [34,36]. Although the involvement of family members may not be directly related to adaptation strategies, having more working family members can mean more money for the family and, as mentioned earlier, financial stability can expedite the process of recovery from the social and economic damages caused by the impacts of climate change. Conversely, it can also mean that there is less diversification in the source of income and, as such, could also constitute a higher risk for the family. Within the context of aquaculture, ref [17] reported that the aquaculture community had encouraged more involvement of women in aquaculture activities in responding to climate change impacts. According to [43], the gender awareness programme in the aquaculture business had accentuated the issue of gender equity in all aquaculture rights systems, which would minimise the domination of males in the aquaculture industry. This would eventually provide women with more opportunities to work in this industry and reduce their reliance on the head of the household in generating income for the family. Some of them have taken their children out of school to help their families to earn extra income and sustain their livelihood [36].

3.2.3. Facilities

Fourteen of the 20 studies focused on the facilities, as the adaptation practice identified in this review. This systematic review found that two studies focused on a change of diet (CD) as the subtheme for facilities, 13 studies focused on cage management (CM), three studies focused on the warning system (WS), three studies focused on technology management and three studies focused on natural barriers (NB) (refer to Table 3).

Change of Diet (CD)

The study by [15] found that there is a distinct need for carrying out a caution assessment on farmed animals and their food, particularly for farming in coastal and marine environments since temperatures and other local environmental conditions affect the health and welfare of cultured animals. As such, the dietary needs of reared animals will change if temperatures begin to grow too hot or cold, so cultured animals' diets will need to be changed in order to keep them healthy and to induce growth. The same view was discovered by [34] when they found that AC needed to focus on providing nutritious foods with a low carbon footprint in rearing their animals when facing changing temperatures caused by climate change.

Cage Management (CM)

Cage management is another appropriate adaptation practice to climate change exercised by AC. The research papers by [15,16,33] said that AC tend to use deeper and thicker nets to protect the cages in order to lessen the impacts of extreme weather such as floods, while [32,37] noted that AC need to develop additional river cages due to the effects of climate change, given that the effects of climate change are more severe in pond aquaculture systems due to their dependency on the soil content and the issue of water quality in pond systems. In their efforts to reduce the impacts of rising sea level, the authors of [35] reconstructed pond dykes through earth-filling that would make them stronger and wider while at the same time dewatering the saline water to maintain good water quality. The authors of [38] reported that AC in Bangladesh have increased the heights of the embankments around shrimp ponds as a way to prevent fish from escaping during inundation resulting from extreme rain in a short duration or tidal flood.

The impacts of climate change, such as warmer temperatures and floods, affect the quality and quantity of reared fish. These changes result in lower yields and one of the ways to adapt to this is by reducing the use of sources and energy while managing their cages. According to [41,42,44] AC had reduced their stocking densities in cages to decrease the energy costs of aeration and pumping as one of their adaptation practices. However, this practice may be seen as a trade-off in terms of potential productivity. The authors of [44] also added that the most obvious option for any operation is to make structural adjustments where possible to reduce the reliance on expensive, direct energy sources such as fuel. In addition, ref [44] mentioned that AC had reduced their reliance on expensive, direct energy sources such as fuel and they needed to invest in newer, more efficient vessels, modify hull designs, change engine type (using hybrid propulsion such as diesel + electric + battery), replace diesel with alternatives such as electricity, natural gas, or biodiesel, and integrate alternative power sources on board (auxiliary power). They can also attempt direct energy inputs to maintain water quality at the farm-level or flow-through rearing environments and other systems where ecosystem services maintain water quality in place of fossil-energy-intensive processes. Additionally, ref [34] noted the same practices when they reported that AC audited their consumption of energy that had been used to identify how to reduce the consumption of fuel.

The authors of [6], on the other hand, found that AC depend on rainwater and reserve water for their farms to survive the impacts of climate change. In this case, they built infrastructures to hold rainwater as their reserve. This adaptation practice ensured that they had an adequate water supply, which is highly necessary following extreme weather (e.g., cyclones) that typically damages water supply infrastructure (e.g., tube-wells).

The authors of [39,41] conceded location diversity as one of the strategies to enhance the rearing resiliency towards climate change impacts, as some inland areas are less vulnerable and exposed to climate change due to seasonal factors, namely the range of temperatures and being at higher elevations than coastal zones. Some of the AC have also taken the initiative to transfer their aquaculture farms to inland areas [39]. The authors of [32] mentioned that AC transferred their farms to rivers and small streams because the water supply was naturally replenished from receiving regular rainfall, thereby reducing the impacts of climate variability and maintaining water quality at a low cost.

In a study by [15], they that noted seasonal changes cause temperatures to vary over several weeks and to address this issue, AC have identified possible risks and opportunities between farm locations. Research by [16] highlighted a similar issue, as environmental changes caused the entire aquaculture output to die-off in the bay area. The elevated water temperatures in that area, for example, exceeded the optimum temperature range of 16–20 Celsius. At the same time, heavy rain had led to respective falls in salinities, which meant that environmental conditions reached lower levels of physiological salinity tolerances. To respond to these changes, migration of the aquaculture farm to a better location is required.

Warning Systems (WS)

Studies by [16,17,34] on AC established a reliable early warning system (WS) as a proactive response to potential threats caused by climate change. This emergency system protects not only the entrepreneurs but also their cultured livestock. The paper by [17] mentioned that the WS need to be improved to better respond to extreme weather conditions such as coastal flooding, cyclones, rising sea levels, and thunderstorms, which have been known to induce adverse effects on aquaculture activities. The research by [34] concluded that the adaptation practice related to WS when facing natural calamities is important since it provides more time for AC to save their resources from the impacts of climate change.

Technology Management (TM)

Technology management has long been relied on by AC since it is one of their adaptation practices in facing the issues associated with climate change [28]. The studies by [17,34,42] for example, noted that AC should improve technology measures for the management of fresh floods. This is because of the rising sea levels and the possible increase in the magnitude and frequency of tropical storms and other natural disasters due to climate change. The main threats could be salinity ingress into bodies of water and the inundation of low-lying areas, with the resultant loss of fertile agricultural lands in coastal areas.

Natural Barriers (NB)

The authors of [17] noted that storm surges and rising sea-levels could be combated by planting more mangroves in coastal areas. Cyclonic weather events wreak havoc on aquaculture communities in multiple ways, such as preventing AC from carrying out aquaculture operations as well as causing infrastructural damage to the key equipment associated with their economic activities. Increasing the numbers of mangroves in these areas could be the best solution to reduce these impacts. The authors of [34] suggested that aquaculture infrastructure built near to coastal areas is vulnerable to more frequent flooding and rising sea-levels, and the most efficient mitigation strategy to practice is to plant more mangroves in coastal areas. In India, the AC planted various types of trees (fruit and wood trees) on pond dykes to strengthen the dykes [35].

3.2.4. Temperature

Four of the 20 studies focused on temperature as an adaptation practice to climate change by AC. In this systematic review, two studies were found to focus on temperature tolerant strains (TS), and three studies focused on seasonal data monitoring (SD) as a subtheme of temperature (see Table 3).

Temperature Tolerant Strains (TS)

Temperature tolerant strains (TS) are one of the temperature subfactors mentioned by researchers as practice undertaken in an attempt to adapt to climate change. The author of [15], for instance, found in his article that AC should be more selective in their breeding programmes to produce more TS since temperature plays a key role in the growth of cultured fish. It is important to have the right temperature as the health of the cultured fish stock is influenced by temperature and other local environmental conditions. The authors of [17] shared similar views when suggesting that AC should enhance the use of suitable inland water bodies through breeding culture-based animals and appropriate stock enhancement mechanisms. Suitable inland water will offer the right temperatures for culture-based animals to attain better rates of growth and resistance to climate change exposure and other associated vulnerabilities.

Seasonal Data Monitoring (SD)

The authors of [15] found that aquaculture entrepreneurs have acquired long-term monitoring and data collection programmes on the temperature around their farms (especially those located on the coast). Such information enables them to evaluate production

changes in the future; for example, temperature projections can be used in bio-energetic models to simulate the potential growth of farmed animals and identify possible risks and opportunities between farm locations. Likewise, ref [16] also concluded that AC built monitoring stations within the bay area, which provided environmental data that helped to record and predict dynamics, and allowed some form of preparation for the potential consequences of developing climate change events in the future. The research by [34] noted that AC developed a database on the impact of climate change based on data monitoring, which allowed them to have data related to climate change events on an annual and monthly basis.

3.2.5. Financial

Twelve of the 20 studies considered in this systematic review focused on the financial aspect of facing climate change. Here, three studies concentrated on financial access (FA), three studies on government support (GS) and nine studies on job diversity (JD) (see Table 3).

Financial Access (FA)

Financial access was highlighted by [16] concluding that AC have joint savings with aquaculture farmer associations, which enables them to accommodate any emergency that they might have. Climate change is forecasted to become worse in the future and is sometimes very unpredictable. Extreme weather, such as strong wind, can suddenly hit an area and cause damages to public amenities, and having such a kind of emergency savings is crucial to expedite the recovery process. In addition to savings, ref [33] in a separate study concluded that AC had explored access to bank credit and bank loans, which were necessary to expedite their aquaculture activities. Although applying for loans involves much bureaucracy and sometimes high interest rates, this strategy allows the AC to acquire more money to invest in labour and capital. The research by [36] found that AC opted for loans from several sources, such as local moneylenders, NGOs and wholesalers with high interest, an option that actually forced them deeper into the poverty trap.

Government Support (GS)

Regarding financial support, the government also plays a major role, which is highlighted by [16]. They concluded that government support (GS) is typically in the form of affordable credits and rapid/effective monetary assistance with the reconstruction of damaged infrastructure. Additionally, ref [17,41] noted that the government had secured national funding for aquaculture farmers to compensate them for their losses due to extreme weather events. Most were compensated in terms of cash, while some received fish stocks or feed. Related government agencies have likewise established a microcredits system that allows aquaculture farmers to obtain affordable credits quickly, and this expedites the process of recovering from the damages they suffered from the climate change-related events.

The research by [17] reported that AC acquired aquaculture insurance as an adaptive measure to the impacts of climate change. One potential impact of climate change is the increase in the frequency of extreme weather events and the associated damage to the aquaculture sector. Cyclones, for example, may damage equipment and aquaculture facilities, as well as causing disruptions in aquaculture operations. Therefore, acquiring aquaculture insurance offers a guarantee that AC and their property are protected from the most severe of the risks posed by climate change.

Job/Livelihood Diversity (JD)

Job/livelihood diversity is an important adaptation practice, as one tends to have more sources of income and an increased capability to find new ways of doing things; hence, this enables people to sustain their living standards [40]. The authors of [14] reported that AC have diversified their sources of income by working in the highlands and diversifying into coffee production during the flood season, and some have even opted to find jobs in cities

as construction workers, hairdressers, or small entrepreneurs. The study by [34] further added that AC also considered working in mangrove conservation projects and initiatives to gain extra income. Participating in local tourism to prevent potential deterioration of the social conditions in aquaculture communities was also associated with climate change.

Climate change's impacts, such as flood and drought, have resulted in low productivity. Both [14,38] concluded that among the adaptation strategies that were practised by AC, a common one is diversifying their income sources by their involvement in rice cultivation activities and rearing livestock. This has given AC the opportunity to generate additional income and to cover losses incurred by the decreased productivity of their aquaculture. In addition, ref [34] added that AC have also practised the traditional method of adopting the integrated farming system where farmers have developed and mastered the technique of below-sea-level cultivation. This system is unique since it contributes remarkably well to the conservation of biodiversity and ecosystem services, including several livelihood services for local communities. Within this review, internal diversification refers to how AC are diversifying their aquaculture practices in order to sustain their livelihoods.

Climate change may have a detrimental effect on certain species but there are species that are able to survive and tolerate the impacts. This situation stimulates AC to diversify their rearing types and lessen their reliance on single type of rearing. This diversity also acts as an 'insurance' for them if one or more of the farmed species face problems. The authors of [14] explained that AC reduced their production of monocultures for aquaculture output and placed more emphasis on the mixed aquaculture schemes (crab, shrimp, and fish). Moreover, they refrain from making large investments, although the profit from mixed-culture is significantly smaller compared to monoculture. In Thailand, ref [41] found that farmers have switched species in response to climate-related risks. Most farmers shifted from tilapia to catfish species, which can tolerate low dissolved oxygen levels. Several advantages are offered by mixed-culture systems given the reduction in pollution and lower risk of exposure to diseases. To avoid the impacts of floods, entrepreneurs in Bangladesh and Vietnam have taken initiatives to reduce risks by early harvesting of their undersized shrimp, and selected a fish seed that can better tolerate warmer temperatures [37,42]. Instead of diversifying their reared species, ref [7] discovered that AC had diversified their cultured fish-stock diet.

4. Discussion

This study aimed to systematically analyse the prevailing literature on the adaptation practice towards climate change impacts among AC. The impacts of climate change pose formidable challenges, and adaptation measures must be introduced and practised to minimise the impacts. The extensive review of the literature in this field was sourced from three databases, resulting in 20 articles related to the adaptation practices employed by aquaculture entrepreneurs. The results indicate that the AC have engaged in a variety of practices. The review yielded five main themes, namely governmental, community, facilities, temperature, and financial, from the thematic synthesis. Further analysis produced 18 subthemes.

Within the context of AC adaptation practices towards climate change, it is interesting to observe that government agencies, academicians, NGOs (legal associations and civil society), local communities (men and women), aquaculture associations and the private sector (investors and bank) are actively assisting them in acquiring a better adaptation practice. However, the study by [8] highlighted the importance of any adaptation programme, plan or strategies made for the community to be in line with their needs, ability, and interests. Further, ref [8] added that a needs analysis study should be undertaken to acknowledge what the target groups of the programme want, as ignoring these elements will result in a programme that is not cost-effective, receive a low response and lack cooperation from the target community, which in turn results in the objectives of the programme being difficult to achieve. On the other hand, ref [8] emphasised the importance of these organisations

involving less bureaucracy in their programmes in order to gain maximum response rates from their target groups.

Notwithstanding the above, the application of technology has been proven to strengthen the adaptation practice of the community [15–17,34]. Within the context of this study, technology had assisted the AC with respect to increasing their productivity, monitoring, early warning systems and flash flood management. For example, ref [45] demonstrated how early warning systems had assisted the community in being proactively prepared for dealing with natural disasters (e.g., strong wind; extreme waves) and afforded them with more time to plan, which lessened their vulnerability and exposure towards climate risks and provided them more protection.

Additionally, ref [46,47] confirmed that technology could increase the quantity and quality of their yields, resulting in more cost-effective operations. Nevertheless, not everyone, regardless of age, is comfortable with technology. Those experiencing technophobia (an aversion to or anxiety towards technology) are overwhelmed by the complexity of technology, heavily attached to traditional ways of doing things and possess a negative attitude towards technology [44]. Hence, it is no wonder that some AC are still practising traditional routines and practices which offer them well-known and familiar ways of conducting their aquaculture routines.

Having said that, AC are seen to have adopted certain practices that are environmentally friendly by planting mangroves, which are anticipated to alleviate the risks and offer greater protection [17,34]. A study by [48] confirmed that mangroves could reduce wave height by between 13% and 66%, reduce storm surge height by between 5 and 50 cm/km, and prevent erosion and instead encourage soil build-up in bay areas. Furthermore, entrepreneurs are conserving more energy to better adapt to the impacts of climate change [34,44]. A study by [49] mentioned that relying solely on energy efficiency is unlikely to deliver anywhere near the energy reductions needed in the limited time available. Moreover, they insisted that most energy reduction results from energy conservation, minimising the utilisation of energy-using devices and domestic energy (e.g., heating and cooling devices), which eventually places less pressure on natural energy resources. The most significant challenge posed by these energy-saving practices, however, is the need for the community to change their lifestyles and behaviours [49].

Nevertheless, livelihood diversification is an important aspect of adaptation practice. Job/livelihood diversification, location diversification, change of diet and the integration of modern and traditional techniques have been practised by AC to sustain their livelihood and well-being [7,14–16,34,39]. Such diversification suggests that flexibility, interest in change, and ability to explore new opportunities are important elements of sustainable livelihood and are an important aspect of their adaptation practice [8]. For example, ref [50] demonstrated that culturing varies with species; and integrating scientific culture practices with traditional approaches involves high economic viability, resulting in a return on investment (ROI) exceeding 100%. In addition, ref [51,52] stated that diversification of livelihood aspects and varying socio-economic routines are important strategies and will help them AC refrain from falling victim to the 'specialisation trap'; a situation where the individual is heavily reliant on one activity or practice for their livelihood.

Within the context of this review, women are encouraged to participate in aquaculture activities, which this is expected to strengthen adaptation strategies [17,34,43]. This practice will also reduce the vulnerability of women towards climate change impacts since they make up the majority of the world's poor, are more dependent on environmental stability and face social pressures, including economic and political barriers that limit their adaptation ability [53]. There is no doubt that women can achieve success in this adaptation strategy, as [54] emphasised that women are effective agents of adaptation. Moreover, women possess a strong body of knowledge related to adaptation practices, while their responsibilities in domestic households and communities, as stewards of natural and household resources, offer them the advantage to sustain their livelihoods and prepare against the formidable impact of climate change.

The adaptation of AC can be seen from two perspectives. First, there are what we can call direct adaptation strategies. This refers to a strategy practiced with the main aim of avoiding or minimizing the impacts of climate change. For example, operators may use thicker nets in an effort to reduce the effects of flooding or move their aquaculture fish-stock to temporary ponds in response to low river water levels caused by droughts. Direct adaptation strategies demonstrate a community's readiness, awareness and alertness, while at the same time demonstrating their skills and knowledge on the best way to adapt and respond to climate variability. Secondly, this review also looks at indirect adaptation strategies, where the main aim is not intentionally to adapt to the impacts of climate change. For example, the AC is found to have a long-term financial plan, saving, making loans, diversifying sources of employment and income. Obviously, they do this to have a better income, strengthen their financial stability, in preparation for the future or to meet their social and economic needs as their norms. Although it is indirect, these 'unconscious strategies' can help AC during emergencies, including efforts related to minimizing or responding to the impacts of climate change. For example, by having multiple sources of income and employment, aquaculture operators have alternative sources if their aquaculture yields are reduced due to major floods or prolonged droughts. Having sufficient savings can also expedite the process of recovering from any damage they suffered from climate change impacts. Both these strategies, whether direct or indirect, are important in AC efforts to reduce the risks posed by climate change. Notably, we cannot say that those with indirect adaptation strategies are failures or adopting weak adaptation strategies; they are actually adapting well to the impacts without realizing it.

5. What Next?

One of the aims of undertaking a systematic literature review is to identify the patterns of previous findings, to know what has been undertaken before and to recommend suggestions on what work needs to be achieved or carried out. The most obvious aspect that should be emphasised is the need to increase the number of studies on AC adaptation practices towards climate change and the consequential impacts. Systematic searching strategies, as adopted in this study, only found 36 related articles in the initial stage and after finalising the searching process, resulted in 20 suitable, high-quality articles. This indicates that there are further opportunities for research and information to be explored within the context of this issue.

Notably, in this study, five main adaptation strategies practised by the AC were highlighted, namely governmental, community, facilities, temperature and financial. Therefore, it is proposed for future scholars to examine the suitability of these adaptation practices. As we are already aware, the changes in climatic conditions are expected to worsen, and there is the distinct possibility that the current adaptation strategies are no longer suitable. Extreme weather conditions, for example, are expected to become more severe and frequent in the future, hence, further increasing the susceptibility of cultured fish to diseases and infections, and also increasing the likelihood of damage to infrastructure and equipment. However, the question remains as to whether the present adaptation strategies, such as transferring the farm's location, data monitoring, changing diets and natural barriers, will still be applicable in future under more severe climatic conditions. This is a significant question that needs to be answered and investigated by future scholars.

Aside from this, future research should also consider widening the focus to include other stakeholders related to aquaculture activities. Additionally, instead of exploring how AC are adapting to the impacts of climate change, data from other aquaculture stakeholders and players, such as aquaculture associations/community, women in aquaculture, government agencies and investors, are important since they provide different perspectives on the best way to respond to the risks of climate variability. Moreover, the diversification of income-generating activities and technology use can be viewed as important adaptation strategies. However, the main obstacle to address is to persuade those who have a strong attachments to and 'specialisation traps' in aquaculture activities to adopt more flexible

processes. This could also include people with technophobia involved in non-aquaculture related activities. Therefore, future scholars should explore strategies to overcome these obstacles as well.

6. Conclusions

The aquaculture industry is an important economic sector worldwide. Statistics have also shown the effectiveness of this industry in strengthening both the social and economic aspects of communities in developing countries. Similar to other industries, the aquaculture industry is facing the formidable impacts of climate change, and accordingly, AC need to adapt to these changes if they wish to survive in this industry in future. The findings of this study are collected from among the few articles in systematically reviewing the existing literature related to how AC are adapting to climate change impacts. All five adaptation practices (Governmental, Community, Facilities, Temperature and Financial) highlighted can be used to inform stakeholders and policymakers about current practices and to guide them on aspects and other factors that they need to consider in any plan to strengthen the adaptation strategies among the AC. Additionally, the issues associated with limited studies in this field, the suitability of current adaptation strategies and their applicability in future, the need to study other aquaculture players and strategies to overcome the 'specialisation trap' and technophobia need to be considered by future scholars.

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