Seaweed Supply Chain Risk Identification in Sabah Using Fuzzy Failure Mode and Effect Analysis

To cite this article: Mohd Mahmud @ Mansor and Nitty Hirawaty Kamarulzaman 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **549** 012096

View the article online for updates and enhancements.

Seaweed Supply Chain Risk Identification in Sabah Using Fuzzy Failure Mode and Effect Analysis

Mohd Mahmud @ Mansor[1,2] and Nitty Hirawaty Kamarulzaman[2*]

[1] Dept. of Agro Based Industry, Fac. of Agro Based Industry, Universiti Malaysia Kelantan, Locked Bag 100, 17600 Jeli, Kelantan
[2] Department of Agribusiness and Bioresource Economics, Faculty of Agriculture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

E-mail: nitty@upm.edu.my

Abstract. *Kappaphycus* sp. and *Eucheuma* sp. were cultivated in Sabah, Malaysia, mainly to extract a compound called carrageenan which used in various industries including human food, pet food, fertiliser, and pharmaceutical. As any agricultural activities, seaweed industry also full with risks and uncertainties. This study hence was conducted to identify risk sources along the supply chain (SC) of seaweed cultivated in Sabah, Malaysia. Data were collected using face-to-face, in-depth interview with Key Informants (KIs) (n = 33). Interviews were transcribed and analysed using thematic analysis using ATLAS.ti. The analysed data then were further analysed using FMEA (Failure Mode and Effect Analysis) in integration with Fuzzy set theory for risk prioritisation. The result has shown that farmers faced 19 unique risks, while intermediaries 13 risks, and 16 risks on the customers part. The analysis also showed that the three most critical risks for with the highest fuzzy RPN number is exchange rate fluctuations, highly volatile global seaweed price and followed by changes in government policy. This research has successfully identified, categorised and assessed 18 most important risk sources that have the probability of disrupting the seaweed supply chain in Sabah. Should stakeholders or policymakers like to ensure the sustainability of the industry, those are the risks that should be paid more attention to increase the resilience of the SC.

1. Introduction

Seaweed, both macro- and macroalgae, can be divided into three main groups according to the colour of their pigments. Those which contained red pigment were grouped into Rhodophyta, while taxonomists classified seaweed with green pigment as Chlorophyta, and lastly, Phaeophyta is a group belonged to seaweed with brown pigment [1]. Other than its ecological importance, community living by coastal regions has been exploiting seaweed for centuries as a food source [1] which rich in calcium, iron, iodine, vitamins, natural antioxidants and proteins. Since last a few decades, many pharmaceutical firms also started to look toward seaweed as a new source for new drugs [2] such as antiviral agents against human immune deficiency virus (HIV) [3] thyroid goitre [4], cardiovascular diseases, osteoarthritis, and diabetes, and anti-ageing and anaemia [1].

Another type of red seaweed, Kappaphycus, and Eucheuma is the primary source of a phycocolloid called carrageenan [5]. The phycocolloid is mostly used because of its gelling capability, especially in the dairy industry since ancient times in China, Ireland, Britain and Europe. Carrageenan has been used as a stabilizer in dairy-based products such as cheese, ice cream, pudding, and milk [5], sausages, cheaper and processed meat [6]. Kappaphycus and Eucheuma are abundantly cultivated in Indonesia, the Philippines and Malaysia [7].

Most of the market for seaweed cultivated in South East Asia is for the carrageenan industry [8]. Hence the majority of farmers prefer to plant K. alvarezii than any other species such as Eucheuma because the former contained a higher percentage of ϰ–carrageenan [6] thus securing better price in the market. Kappaphycus and Eucheuma made up to the list of seven most cultivated seaweed taxa in the world [9].

Since the 1960s, due to the development of new food products [10] and more processed food, demand for seaweed especially carrageenophytes is expected to increase substantially [11, 12]. For example, more research has been done on the potential of seaweed for industrial uses which open up a new market for seaweed, beyond regular commodity for food and feed [13,14], and source of polysaccharides [15] into biomass and bioenergy [16], biofertilizers [17], cosmeceuticals, nutraceuticals, and pharmaceuticals [18,19,20].

It is estimated that the market value of seaweed cultivation to be worth around USD4.2 billion, constituting almost half of all marine aquaculture products [21]. Moreover, the fact that this industry employs close to half a million workers around the world [11] give it more reason to be sustainably managed.

The first objective of this study is to map the structure of seaweed supply chain in Sabah; secondly to identify every possible risk source that might exist along the supply chain, and the third objective is to prioritize those risks based on its fuzzy integrated value.

2. Literature Review

2.1 Definition of Risk

Like any other agricultural activities, seaweed and its by-products are not shy of risks. Risk itself can be defined in various ways, depends to which perspective it is looked from [22,23,24]. For example, according to Zsidisin [25], risk can be defined scientifically as a function of a probability of occurrence and the severity of its adverse effect. Meanwhile, van Mieghem [26] defined risk as "a possible undesirable consequence of uncertainty". Some authors also agreed that risk cause undesirable deviation from the original objective [27] or when the measured outcome is lower than the expected value [28,29].

In contrast to the definition of risk; however, researchers are still having a problem to come with a concession regarding the most precise definition of supply chain risk [22]. The paper from Ho *et al*. [29] defined supply chain risk as "the likelihood and impact of unexpected macro and/or micro-level events or conditions that adversely influence any part of a supply chain, leading to operational, tactical or strategic level failures or irregularities". It emphasises on two criteria; unexpected events and the adverse impact of the said event towards a supply chain, in agreement with many other prior authors.

2.2 Supply Chain Risk

Risks in a supply chain can be divided into two broad categories namely macro and micro [29] or may also referred as catastrophic and operational [30]. Macro risks or disruptions are one that exists outside of the supply chain and still has a significant impact on the member of the chain such as climate change, natural disaster, political instability, and economic uncertainty. Meanwhile, micro factors refer to risks that might exist or cause by the activities performed directly by the players in the said supply chain which can be further divided into five subcategories; demand, manufacturing, supply, information, transportation, and financial.

Disruption risk such as climate can play a vital role as a risk source in agriculture. For example, the geographical location of East Sabah exposed the industry to a strong wind blowing starting from October until February during the northeast monsoon season [31]. During this period, wind motion in the atmosphere are capable of influencing sea current which will adversely affect the physicochemical complex of the environment such as seawater temperature, salinity, and light attenuation as shown in a study by Trung [32]. The unfavourable underwater condition is taxing to the seaweed growth performance, which can be observed from lower biomass gain and smaller thalli. The size of the thalli and roughness of the sea is directly related and can reach more than 10% [33,34]. The location of seaweed farms which usually located in open sea increase its vulnerability to storms and possibly typhoon which has been reported in the Philippines [35] and Gilbert Island [36].

On the other hand, another risk source, for example, demand risk can exist in a few forms; positive and negative. Sodhi [37] discussed demand risk as a last-minute change in order quantity which prompts a company to either decrease or lowers their inventory. Negative demand risk occurs when final quantity which ordered by the end customer is lower than inventory, which in the end will create surplus while on the other hand, positive demand is when final quantity ordered is higher than inventory available.

2.3 Fuzzy Failure Mode and Effect Analysis (Fuzzy FMEA)
This research attempted to apply fuzzy Failure Mode and Effect Analysis (FMEA) on the first two processes of SCRM; identification and evaluation of risks by using seaweed industry in Sabah as a case study. Introduced in the 1960s, Failure Mode and Effect Analysis (FMEA) is one of tool that was widely used in manufacturing, engineering and aerospace [38]. The method called for the derivation of Risk Priority Number (RPN) by calculating the severity (S) of risk, its occurrence (O), and also the ability to detect (D) a risk before it materialised [39]. However, this method is not without its weaknesses. Risk Priority Number (RPN) has been criticised by many researchers [40,41,42] mainly due to its assumption that every element; S, O, and D are equally important. Other than that, classical FMEA also requires linguistic input to describe risks from domain experts who are considered too subjective and are not quantitatively precise [43].

The integration of fuzzy set theory to FMEA was introduced by Zadeh [44]. Fuzzy can assign membership values expressing the degree to which a certain value of a variable fits a linguistic concept. Accordingly, a gradual transition between different states of a variable can be achieved through the use of membership functions (MFs). Moreover, the fuzzy set theory also capable of managing situations in which accurate data are scarce or hard to collect, or circumstances where information are explained in linguistic and subjective terms [38].

3. Research Method
This study was conducted using primary qualitative data gathered using face to face interview and structured questionnaire instrument. For the purpose of simplification, the methodology was summarised in a diagram below.
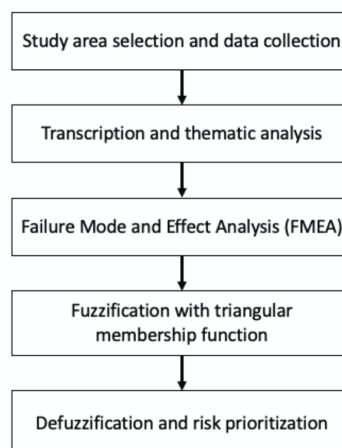
Figure 1. Flow chart summarising methodologies used in this study.

3.1 Study Area and Data Collection
Data collection was conducted at the largest producer of fresh eucheumatoid seaweed by area; Semporna, Sabah. In the area, most of the production was centred at Sebangkat Island, Bum-Bum Island and Manampilik Island which made of 83% of total production [45]. The interview was conducted in two phases to 33 respondents who are directly involved in the industry where 27 of them were owner or manager of seaweed farms, four collectors, and processors. All respondents were selected using non-probability sampling through purposive sampling, and snowball technique was used to identify a key player in the industry. These respondents or Key Informants (KIs) were considered as a domain expert on their respective role in the seaweed supply chain.

A semi-structured questionnaire was adopted and modified based on a framework by Jaffee *et al*. [46]. Recorded interviews were immediately transcribed verbatim and analysed using Atlas.ti version 8.2.4 for Mac. Transcribed interviews were then subjected to thematic analysis [47]. The second stage of data collection was held guided by a failure mode and effects analysis (FMEA) based on Stamatis [48].

3.2 Data Analysis.

Failure Mode and Effect Analysis (FMEA) required respondents to rate risks identified during the first phase of data collection according to its severity (S), detection (D), and occurrence (O) between 1 to 10 as detailed in Table 1 to 3. Severity refers to the magnitude of a risk, while detection is the capability of a system or procedure to discover risk potential before it happens. Lastly, the occurrence is the frequency of a particular risk factor to occur [48]. Consequently, for every risk identified (*i*), a risk priority number (RPN) was calculated using the following equation (1) below.

$$RPN_i = Severity\ (S_i) \times Occurence\ (O_i) \times Detection\ (D_i)$$

However, the value obtained from calculating RPN resulted in a vague and imprecise value. Besides, the rating by domain experts which used linguistic terms is not very objective [49]. Moreover, RPN also could not differentiate the importance of every factor (S, O, and D) weight [50]. Hence, to overcome the issue, this study integrated FMEA with fuzzy membership function. Fuzzy set theory has the capability to provide objective values from the vague linguistic variables. It also could assign a different weight to every factor.

3.2.1 Risk Assessment with Fuzzy Membership Function.
To simplify the process of fuzzification for severity, occurrence, and RPN, this study used a triangular membership function as shown in Equation (2) where *a* and *b* are respective top and bottom ends while μ is the vertex triangle.

$$\mu_A(x) = \begin{cases} (x-a)/(b-a), & for\ a \le x \le b \\ (c-x)/(c-b), & for\ b \le x \le c \\ 0 & otherwise \end{cases}$$

On the other hand, a trapezoidal membership function was used and is shown in Equation (3).

$$\mu_A(x) = \begin{cases} (x-a)/(b-a), & for\ a \le x \le b \\ 1 & for\ b \le x \le c \\ (d-x)/(d-c), & for\ c \le x \le d \\ 0 & otherwise \end{cases}$$

Finally, a method of "left and right rating of fuzzy number" was used to defuzzify and prioritized the result into concrete value. All three parameters of FMEA were multiplied as fuzzy numbers to obtain fuzzy RPN, and the result is measured as a triangular fuzzy number. The Fuzzy RPN then defuzzified using "left and right rating of fuzzy number" followed by risk prioritization.

Table 1. FMEA Scale and Criteria for Severity (S)

Criteria	Effect	Triangular Fuzzy number	Rank
No effect	None (NO)	(0 , 0.1 , 0.2)	1
Very minor effect on product or system performance.	Very minor (VM)	(0.1 , 0.2 , 0.3)	2
Minor effect on product or system performance.	Minor (MI)	(0.2 , 0.3 , 0.4)	3
Small effect on product performance. The product does not require repair.	Low (LO)	(0.3 , 0.4 , 0.5)	4
Moderate effect on product performance. The product requires repair.	Moderate (MO)	(0.4 , 0.5 , 0.6)	5
Product performance is degraded. Comfort or convince functions may not operate.	Significant (SI)	(0.5 , 0.6 , 0.7)	6
Product performance is severely affected but functions. The system may not operate.	Major (MA)	(0.6 , 0.7 , 0.8)	7
Failure is hazardous and occurs without warning. Its system is inoperable.	Extreme (EX)	(0.7 , 0.8 , 0.9)	8
Failure involves hazardous outcomes and/or noncompliance with government regulations or standards.	Serious (SE)	(0.8 , 0.9 , 1)	9
Failure is hazardous and occurs without warning.	Hazardous (HA	(0.9 , 1 , 1)	10

It suspends the operation of the system and/or involves
noncompliance with government regulations.

Table 2. FMEA Scale and Criteria for Occurrence (O)

| Criteria	Effect	Triangular Fuzzy number	Rank
Failure unlikely. History shows no failures.	Remote (R)	(0 , 0.1 , 0.2)	1
A rare number of failures likely.	Low B (LB)	(0.1 , 0.2 , 0.3)	2
Very few failures likely.	Low A (LA)	(0.2 , 0.3 , 0.4)	3
Few failures likely.	Moderate C (MC)	(0.3 , 0.4 , 0.5)	4
Occasional number of failures likely.	Moderate B (MB)	(0.4 , 0.5 , 0.6)	5
Moderate number of failures likely.	Moderate A (MA)	(0.5 , 0.6 , 0.7)	6
Frequent high number of failures likely.	High B (HB)	(0.6 , 0.7 , 0.8)	7
High number of failures likely.	High A (HA)	(0.7 , 0.8 , 0.9)	8
Very high number of failures likely.	Very high B (VHB)	(0.8 , 0.9 , 1)	9
Failure almost certain. History of failures exists from previous or similar designs.	Very high A (VHA)	(0.9 , 1 , 1)	10

Table 3. FMEA Scale and Criteria for Detection (D)

Criteria	Detection	Triangular Fuzzy number	Rank
Current controls almost always will detect the failure. Reliable detection controls are known and used in similar processes.	Almost certain (AC)	(0 , 0.1 , 0.2)	1
Very high likelihood current controls will detect the failure.	Very high (VH)	(0.1 , 0.2 , 0.3)	2
Good likelihood current controls will detect the failure.	High (H)	(0.2 , 0.3 , 0.4)	3
Moderately high likelihood current controls will detect the failure.	Moderately high (MH)	(0.3 , 0.4 , 0.5)	4
Medium likelihood current controls will detect the failure.	Medium (M)	(0.4 , 0.5 , 0.6)	5
Low likelihood current controls will detect the failure.	Low (L)	(0.5 , 0.6 , 0.7)	6
Slight likelihood current controls will detect the failure.	Slight (S)	(0.6 , 0.7 , 0.8)	7
Very slight likelihood current controls will detect the failure.	Very slight (VS)	(0.7 , 0.8 , 0.9)	8
Remote likelihood current controls will detect the failure.	Remote (R)	(0.8 , 0.9 , 1)	9
No known controls available to detect the failure.	Almost impossible (AI)	(0.9 , 1 , 1)	10

4. Results and Discussion

4.1 Seaweed Supply Chain in Sabah
As presented in Figure 2, the seaweed supply chain in Sabah can be modelled as a network of three subsystems; supplier of fresh and dried seaweed, multilevel of middlemen, and customers. These subsystems were designed based on their nature of activity in the supply chain. The supply chain is integrated under a push paradigm where production is running almost the whole year without any forecasting on demand done by farmers since 90% of them are small farmers, non-citizen [51] without much access to market intelligence or information.
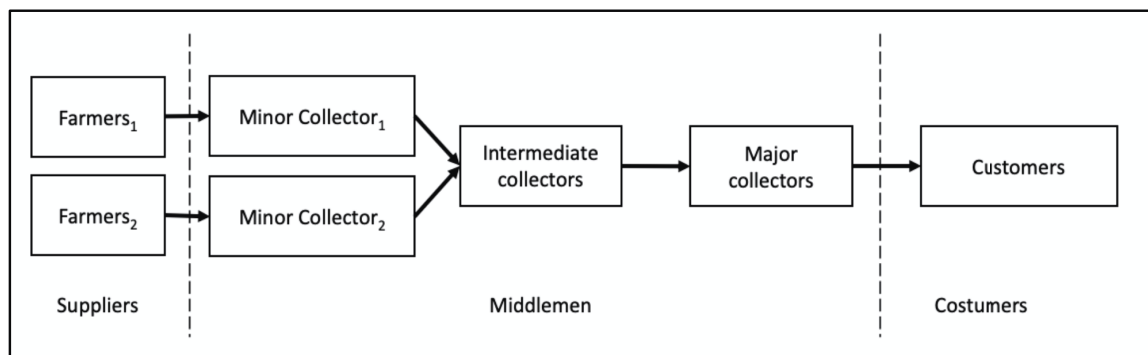
Figure 2. Supply chain of seaweed industry in Sabah, Malaysia

Main activities of seaweed farmers were planting, harvesting, drying, and short-term storage. Since the cultivation activity doesn't need any input of fertilizer, the only recurring resources are the planting materials such as seed or *bibit*. Every four (4) cycles which took 45 days each, the seed will be exchanged between farmers from a different area as the genetic quality will become intolerable after the fifth generation. They will produce as many dried seaweeds as possible to be sold to a minor collector or *agents at sea*.

These agents will collect and evaluate the quality of the dried seaweed on individual farmers small sea platforms, scattered across the sea. The quality of dried seaweed is determined by the Moisture Content (MC) where 35% to 40% are deemed acceptable [52]. If the MC is higher than 40%, the agent will penalize the farmer by offering a lower price. Other than that, this member of the supply chain also acts as a marine logistics provider by arranging boats and labour to collect the dried seaweed on each sea platforms. Agents at sea and farmers share a special relationship as they work on trust, where a similar situation can also be found in Indonesia [8]. Sometimes, agents at sea act as a credit provider or food supplier to these farmers as a duration for payment from more significant collectors were not consistent, and it could take up to three months. These agents also work like a mafia, in a way that each agent is taking care a group of farmers of a specific area on the sea and the farmers won't sell their harvest to any other agents.

According to Sade *et al*. [53], there can be as many as five layers of agents before the harvested seaweed reached processors. Major collectors play a very crucial role in the supply chain as they provide ground logistics, storage facility, and marketing. A final subsystem in the network is customers, which composed of a few groups. The first and largest group customer is Tacara, a local private limited company which located in Tawau. This company processed dried seaweed into semi-refined, food-grade carrageenan for the international market, mostly to China and European countries. The second group of customers is from food and beverage company which bought seaweed in a much smaller amount to be used as an ingredient in their products. The third group is overseas buyers, mostly from the Philippines, and China.

4.2 Risk Identification, Categorization, and Assessment using Fuzzy FMEA
Risk identification along the supply chain was conducted to assess the most influential risks towards every member of the chain. As in Table 4, risks were assigned based on each member of the supply chain; farmers, middlemen, and customers. Farmers faced 19 unique risks, while intermediaries 13 risks, and 16 risks on the customers part. The risks on each member were categorized into seven risk types, based on the definition by Ho *et al*. [29], and were then assigned a risk rating by domain experts. Afterwards, its respective RPN was calculated by using Equation (1). The rate of each FMEA components (S, O, and D) was presented in Table 4 as the mean value. The higher the RPN, the more critical the risk is towards the system. To enable priority ranking to those identified risks, a criticality analysis was conducted.

Based on Table 4, the three most critical risks for with highest fuzzy RPN number is exchange rate fluctuations, highly volatile global seaweed price and followed by changes in government policy. Most of the largest customer for major middlemen and dried seaweed processor in Sabah is from overseas such as China, the Philippines, and eastern European countries. The business transaction which was conducted in US dollars makes profits and losses heavily dependent on the movements of exchange rates [54]. Radical changes in exchange rates might happen in a

short period, causing companies dealing internationally to lose a significant amount of profit. The economist has listed this risk as one of the top concern among executives [55].

Table 4. Risk assessment of seaweed supply chain in Sabah using FMEA

Supply chain member	Risk type	Code	Risk factors	Severity (S)	Occurrence (O)	Detection (D)	RPN	Defuzzy RPN	Rank
Farmers	Disruption	FD1	Security (ESSZONE)	4	5	7	140	0.1395	4
		FD2	Climate	7	3	7	147	0.1479	3
		FD3	Government policy	8	2	9	144	0.1516	2
		FD4	Fuel price fluctuation	2	5	10	100	0.1129	6
	Demand	FDe1	Too many middlemen	3	10	1	30	0.043	14
	Manufacturing	FM1	Uncertain of seaweed yield	7	5	4	140	0.1395	4
		FM2	Labour supply shortage	8	7	2	112	0.1197	5
	Supply	FM3	Hard to get seeds	5	5	2	50	0.0568	10
	Information	FI1	No information on current price of dried seaweed	4	10	1	40	0.0553	11
	Transportation	FT1	Jetty is too far from farm	6	7	1	42	0.0548	12
	Financial	FF1	Fluctuating seed price	5	5	3	75	0.0795	7
		FF2	Fluctuating dried seaweed price	6	3	9	162	0.1624	1
		FF3	No control over factory price	5	10	1	50	0.0677	8
		FF4	High planting cost	7	3	2	42	0.0492	13
		FF5	Payment from buyer delayed	7	7	1	49	0.0633	9
Middlemen	Disruption	MD1	Government policy	5	2	9	90	0.0981	5
		MD2	Fuel price fluctuation	4	3	10	120	0.1294	2
		MD3	Exchange rate fluctuation	4	4	10	160	0.1664	1
	Demand	MDe1	Not enough inventory to cater demand	6	2	2	24	0.0305	8
		MDe2	Sudden change of orders	3	2	10	60	0.0305	8
	Manufacturing	MM1	Product damaged during storage	5	2	2	20	0.0258	9
	Supply	MS1	Unstable raw dried seaweed supply	5	5	4	100	0.1023	4
	Information	MI1	Error in forecasting of supply and demand	3	2	5	30	0.0361	7
	Transportation	MT1	Poor jetty infrastructure	2	2	1	4	0.007	11
		MT2	Transport broke down	6	3	3	54	0.0598	6

Financial	MF1	Fluctuating seaweed price	2	2	6	24	0.0305	8
	MF2	No control over factory price	1	10	1	10	0.0184	10
	MF3	Payment from customers delayed	6	7	3	126	0.1282	3
Disruption	CD1	Exchange rate fluctuation	7	8	4	224	0.2156	1
Demand	CDe1	Not enough inventory to cater demand	6	4	3	72	0.0769	6
Manufacturing	CM1	Machine broke down	7	5	2	70	0.0774	5
	CM2	Low product quality due to manufacturing error	5	2	1	10	0.0154	13
	CM3	Product damaged during storage	3	7	3	63	0.069	7
Supply	CS1	Late delivery of dried seaweed	5	5	1	25	0.034	10
	CS2	Low quality of raw material	5	5	1	25	0.034	10
	CS3	Instable supply of dried seaweed	7	7	2	98	0.1056	4
	CS4	Inconsistent raw material quality	5	2	3	30	0.0361	9
Information	CI1	Error in forecasting of supply and demand	4	2	5	40	0.0464	8
Transportation	CT1	Logistics arrangement failure	6	2	2	24	0.0305	11
Financial	CF1	Fluctuating product price	3	7	3	63	0.069	7
	CF2	Fluctuating seaweed price	7	8	3	168	0.1676	2
	CF3	Payment from buyer delayed	5	7	3	105	0.1084	3

(Customers spans the Disruption through Financial rows)

The uncertainty in the price of dried seaweed marked by "price boom". It is a situation where a rapid increase in price in several cycles and followed by a crash. Usually, this happens when the market is flooded with money from China. The impact of the risk also felt by customers as they now will have to compete with a higher price, but with little capital. This phenomenal usually will be followed by a seaweed market crash. However, it is also common for individual involved in the agriculture sector or food system to perceived price volatility as one of the most critical risk factor [56]. One of the management strategies to handle price risk is by having forward contracts [57,58,59] but in Sabah seaweed industry the practice is non-existence. Price risk, as can be seen in this study affect producers and processors, but not so much on the middlemen.

The third risk that was regarded as high in the supply chain is government policy. As presented in Table 4, the reason for this situation is due to the unpredictability of government policy. As an example, the Malaysian government has included seaweed cultivation as one of its entry point projects for NKEA in 2012. This introduction of the new programme came with many changes in policy and implementation and caught both executive agencies and farmers by surprise. As a result, in 2012 the production of seaweed decreased for the first time since 2006 as reported by the Department of Fisheries [60].

5. Conclusion

From this study, it can be concluded that there were three subsystems identified in the seaweed supply chain in Sabah with a unique characteristic of specialized multi-level agents. Besides, this study also successfully attempted to implement fuzzy FMEA in risk identification and assessment of seaweed supply chain in Sabah. The result from the analysis shown that there is the member of the supply chain is interrelated by two types of risks. Farmers and processors were experiencing uncertainty in price risk while at the same time processors and middlemen also facing similar risk in term of fluctuating exchange rate due to their major market are overseas. Future research should expand this study by quantitatively analyse the best risk mitigation strategy to overcome the most critical risks which have been identified in this study.

Acknowledgements

References

[1]   Baweja P, Kumar S, Sahoo D and Levine I 2016 Chapter 3 - Biology of Seaweeds. In Joël Fleurence & I. Levine (Eds.), *Seaweed in Health and Disease Prevention* (pp. 41–106). San Diego: Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-802772-1.00003-8

[2]   Smit J A 2004 *M. J. Appl. Phycol.* **16** 245-262

[3]   Mendis E and Kim S-K 2011 *Adv. Food Nutr. Res* **64** 1-15

[4]   Burtin P 2003 *Elect. J. Environ. Agri. Food Chem.* **2** 498-510.

[5]   Prameela K, Murali Mohan C and Ramakrishna C 2018 Biopolymers for Food Design: Consumer-Friendly Natural Ingredients. In A. . Grumezescu & A. . Holban (Eds.), *Biopolymers for Food Design* (pp. 1–32). Academic Press. https://doi.org/https://doi.org/10.1016/C2016-0-00686-1

[6]   Campbell R and Hitchkiss S 2017 Carrageenan Industry Market Overview. In A. Q. Hurtado, A. T. Critchley, & I. C. Neish (Eds.), *Tropical Seaweed Farming Trends, Problems and Opportunities* (pp. 193–205). Springer.

[7]   Hussin R, Md Yasir S, Kunjuraman V and Hossin A 2015 *Asian Social Science* **11(18)** 1

[8]   Mulyati H and Geldermann J 2016 *Clean Technologies and Environmental Policy* **19(1)** 1-15

[9]   FAO 2016 *The state of world fisheries and aquaculture. Contributing to food security and nutrition for all. The State of World Fisheries and Aquaculture*. Rome, Italy. https://doi.org/92-5-105177-1

[10]   FAO 2018 *The global status of seaweed production, trade and utilization Volume 124*. Rome. Retrieved from http://www.fao.org/3/ca1121en/CA1121EN.pdf

[11]   Hurtado A Q, Critchley A T and Neish L C 2017 *Tropical Seaweed Farming Trends, Problems and Opportunities*. https://doi.org/10.1007/978-3-319-63498-2

[12]   Nor A, Gray T, Caldwell G and Stead S 2016 The Introduction of the Seaweed Cluster Project (SCP) to Optimise Seaweed Production in Malaysia. Retrieved from https://www.researchgate.net/profile/Adibi_Nor/publication/306275750_The_Introduction_of_the_Seaweed_Cluster_Project_SCP_to_Optimise_Seaweed_Production_in_Malaysia/links/57b5df2608aeddbf36e846d7/The-Introduction-of-the-Seaweed-Cluster-Project-SCP-to-Optim

[13]   Fleurence J 2016 Chapter 5 - Seaweeds as Food. In Joël Fleurence & I. Levine (Eds.), *Seaweed in Health and Disease Prevention* (pp. 149–167). San Diego: Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-802772-1.00005-1

[14]   Neori A 2016 Can sustainable mariculture match agri- culture' s output? Retrieved from http://advocate.gaalliance.org/can-sustainable-mariculture-match-agricultures-output/

[15]   Bixler H J and Porse H 2011 *Journal of Applied Phycology* **23(3)** 321-335

[16]   Fernand F, Israel A, Skjermo J, Wichard T, Timmermans K R and Golberg A 2016 *Renewable and Sustainable Energy Reviews* **75** 35-45

[17]   Delaney A, Frangoudes K and Ii S-A 2016 Chapter 2 - Society and Seaweed: Understanding the Past and Present. In Joël Fleurence & I. Levine (Eds.), *Seaweed in Health and Disease Prevention* (pp. 7–40). San Diego: Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-802772-1.00002-6

[18]   Anis M, Ahmed S and Hasan M 2017 *World Journal of Pharmacy and Pharmaceutical Sciences* **6** 1934-1959

[19]   Balboa E M, Conde E, Soto M L, Pérez-Armada L and Domínguez H 2015 Cosmetics from marine sources. In

S. K. Kim (Ed.), *In Handbook of Marine Biotechnology* (pp. 1015–1042). Berlin: Springer Berlin Heidelberg.

[20]   Himaya S W A and Kim S-K 2015 Marine nutraceuticals. In S.-K. Kim (Ed.), *Handbook of Marine Biotechnology* (pp. 995–1014). Berlin: Springer Berlin Heidelberg.

[21]   Winberg P C, Fitton H J, Stringer D, Karpinec S S and Gardiner V A 2014 Controlling seaweed biology, physiology and metabolic traits in production for commercially relevant bioactives in glycobiology. In J. P. Jacquot, P. Gadal, & N. Bourgougnon (Eds.), *Advances in Botanical Research* (pp. 221–252). Sea Plant.

[22]   Baryannis G, Validi S, Dani S and Antoniou G 2018 *International Journal of Production Research* **57(7)** 2179-2202

[23]   Hudnurkar M, Deshpande S, Rathod U and Jakhar S K 2017 *Operations and Supply Chain Management: An International Journal* **10(4)** 182-199

[24]   Rangel D A, de Oliveira T K and Leite M S A 2015 *International Journal of Production Research* **53(22)** 6868-6887

[25]   Zsidisin G A 2003 *Journal of Purchasing and Supply Management* **9(5-6)** 217-224

[26]   van Mieghem J A 2012 Risk management and operational hedging: An overview. In P. Kouvelis, L. Dong, O. Boyabatli, & R. Li (Eds.), *Handbook of integrated risk management in global supply chains* (pp. 13–49). New York: Wiley.

[27]   Tsai C Y 2008 *Decision Support Systems* **44(4)** 1031-1042

[28]   Harland C, Brenchley R and Walker H 2003 *Journal of Purchasing & Supply Management* **9** 51-62

[29]   Ho W, Zheng T, Yildiz H and Talluri S 2015 *International Journal of Production Research* **53(16)** 5031-5069

[30]   Sodhi M S and Tang C S 2012 *Managing Supply Chain Risk* (Vol. 172). https://doi.org/10.1007/978-1-4614-3238-8

[31]   Peng Hului P 2011 *Seasonal monsoon effects on seaweed production in Semporna*. Universiti Malaysia Sabah. Retrieved from http://eprints.ums.edu.my/13178/1/ae0000002825.pdf

[32]   Trung D T 2019 *Journal of Applied Phycology* **31(3)** 1991-1998

[33]   Mollion J and Braud J-P 1993 *Hydrobiologia* **260–261(1)** 373-378

[34]   Iba W, Patadjai A B, Rahim M, Febriyanti F, Hafid H and Armin A 2019 Effect of Different Initial Weight on Growth and Carrageenan Yield of Kappaphycus alvarezii (Gigartinales, Rhodophyta) farmed using Seedlings Produced from Mass Selection Combined with Tissue–Cultured Method. In *IOP Conference Series: Earth and Environmental Science* (Vol. 382, No. 1, p. 012007). IOP Publishing.

[35]   Phillips M J 1998 *Tropical Mariculture* 17-69

[36]   Hepburn C D 2019 9 Local, community-led interventions to address global-scale problems and environmental extremes in coastal ecosystems. *Marine Extremes: Ocean Safety, Marine Health and the Blue Economy*.

[37]   Sodhi M S 2005 *Production and Operations Management* **14(1)** 69-79

[38]   Abdelgawad M and Fayek A R 2010 *Journal of Construction Engineering and Management* **136(9)** 1028-1036

[39]   Islam M S, Nepal M P, Skitmore M and Attarzadeh M 2017 *Advanced Engineering Informatics* **33** 112-131

[40]   Bowles J and Peláez C E 1995 *Reliab. Eng. Syst. Saf.* **50(2)** 203-213

[41]   Pillay A and Wang J 2003 *Reliab. Eng. Syst. Saf.* **79(1)** 69-85

[42]   Puente J, Pino R, Priore P and Fuente D 2002 *Int. J. Qual. Reliab. Manage.* **19(2)** 137-150

[43]   Xu K, Tang L C, Xie M, Ho S L and Zhu M L 2002 *Reliab. Eng. Syst. Saf.* **75(1)** 17-29

[44]   Zadeh L A 1965 *Information and Control* **8(3)** 338-353

[45]   Hossain M S, Bujang J S, Zakaria M H and Hashim M 2016 *Marine Policy* **72** 176-191

[46]   Jaffee S, Siegel P and Andrews C 2008 *Rapid agricultural supply chain risk assessment. World Bank*.

[47]   Braun V and Clarke V 2006 *Qual. Res. Psych.* **3** 77-101

[48]   Stamatis D H 2003 *Failure Mode and Effect Analysis: FMEA from Theory to Execution* (Second). Milwaukee, Wisconsin: ASQ Quality Press.

[49]   Hayati M and Abroshan M R 2017 Risk Assessment using Fuzzy FMEA (Case Study : Tehran Subway Tunneling Operations), *10*(March), 1–9.

[50]   Liu H, Deng X and Jiang W 2017 *Symmetry* **9(8)** 162

[51]   Allerton C 2017 *Journal of Immigrant & Refugee Studies* **15(3)** 250-268

[52]   Dept. of Fisheries 2012 *Manual Pengkulturan Rumpai Laut (Eucheuma dan Kappaphycus)*. Putrajaya, Malaysia: Department of Fisheries.

[53]   Sade A, Ali I and Ariff M R M 2006 *Jati-Journal of Southeast Asian Studies* **11** 97-107

[54]   Kim K and Park K 2014 *Eur. J. Oper. Res*, **237(2)** 634-648

[55]   Economist Intelligence Unit 2009 Managing supply-chain risk for reward. *The Economist*.

[56]   Assefa T T, Meuwissen M P M and Oude Lansink A G J M 2017 *NJAS - Wageningen Journal of Life Sciences* **80** 15-26

[57]   Heyder M, Theuvsen L and Von Davier Z 2010 *J. Chain Net. Sci.* **10(1)** 17-25

[58]   Martin S 1996 *Rev. Mark. Agri. Econ.* **64(1)** 31-44

[59]   Von Davier Z, Heyder M and Theuvsen L 2010 *Int. J. Food Syst. Dyn* **1(3)** 212-223

[60]   Department of Fisheries 2017 *PENGELUARAN RUMPAI LAUT MENGIKUT BULAN DAN NEGERI*.