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TABLE OF CONTENT

After Two Decades of Halal Consumer Research: Is There a Future for Aquaculture Discipline?

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Abstract

This paper aims to understand how scholarly research shaped the aquaculture field since the early 2000s, by taking into consideration the academic literature on halal consumers. We conducted a bibliometric analysis of halal consumer to the aquaculture research discipline by examining the types of documents, style of language used, subject areas, most-cited authors, papers and authors' keywords to draw a general picture of the field. Our results showed that the halal consumer research has been largely designed based on business, management, and accounting disciplines. Nevertheless, since 2019 these disciplines were approaching their maximum limit as evidenced from our findings. Thus, as the field of halal consumer research in these disciplines are 'matured', we view the next most influenced subject areas, the disciplines of agricultural and biological sciences, as the future potential winners in the halal consumer research. Our bibliometrics sets a baseline that will enable scholars to foresee how the field of aquaculture research and halal consumer could directly inform each other in establishing a new area of halal consumer-aquaculture research.

Keywords: Aquaculture research discipline, bibliometrics, halal consumer, Malaysia

Introduction

During the last two decades, interest in sustainable aquaculture has grown to worldwide proportions; various sectors of society are slowly realizing the occurrence of resource scarcity, environmental degradation, population growth, uncontrolled economic growth, and social marginalization (Ahmed, 2018; Jönsson, 2019; Wong & Yong, 2020). For a developing country like

Malaysia, there is a need to match aquacultural sustainability with the development of the halal industry. Tajuddin Abdul Rahman the former Deputy Minister of Agriculture and Agro-based Industry suggested that fish cage aquaculture should be prioritized for investment because it has the potential to be one of the significant income contributors to the economy, with a contribution of RM 2.2 million in July 2017 (The Star, 2017). The big potential investment in aquaculture requires a stable sustainability programme to maintain appropriate temperature, oxygen, pH, turbidity, nitrate, nitrite, ammonia, and phosphate (Baleta & Bolaños, 2016; Sriwahyuni, 2022).

Halal has been proposed as a new scientific discipline that defines, classifies, and studies consumers from an ecological and socio-economic perspective (Iqbal, 2015; Bashir, 2019). New perspectives on halal have allowed us to understand it better, in a more fully integrated manner, on the various factors that govern halal consumers and to develop new technological avenues for the halal industry in a more environmentally sound manner (Ab Rashid & Bojei, 2019). However, most halal works of literature are restricted on the ability to understand and address the fundamental reasons on consumers' trust (Bonne & Verbeke, 2008), concerns (Ireland & Rajabzadeh, 2011), and confidence (Mohamed et al., 2013). There is less emphasis on halal consumers and the direction of aquaculture research. The discussions are limited only to aquafeeds of impure animal wastes like carcass, blood, and pig (Jamaludin et al., 2011).

This limitation is mentioned in this current paper to determine the characteristics of the literature produced on halal consumers since the early 2000s in terms of type, influence, and impact. What are the influence and productivity levels of researchers within the halal consumer research community and the institutions? How would the halal consumer research shape the aquaculture field? To answer these questions, this study used bibliometric analysis techniques to analyze the literature on halal consumer research published between 2005 and 2020 and the community of researchers involved in the production. The methodology used to perform the analysis is discussed in the next section of the paper, followed by in-depth descriptions of the findings that shed light on the 15 years of research in the field of halal consumer. Finally, the paper is concluded with some recommendations in guiding future research on aquaculture that is in line with the findings in this study.

Bibliometric Analysis of Halal Consumer Research

The word 'halal' is not only used in the context of consumables or products used by Muslims. It has a wide scope of applications which covers from meat (Vanany et al., 2019; Fuseini & Knowles, 2020), cosmetics (Suhartanto et al., 2020), trade and financial services (Johan & Hussain, 2019), and food and animal feed (Saidin, 2019; Iqbal et al., 2020). Generally, halal has been understood concerning its absence when 'things go wrong'. From the context of consumerism, halal increases the system's sustainability in terms of human relationships, clothing, manner, and social and business transaction that are parallel to the principles and guidelines specified by Islam.

To present the actual developments in the halal consumer field, the researcher searched the Scopus databases for the entire period for which these databases provide online coverage. It was found that the databases cover a period of more than two decades because the oldest paper was published in 2005. To date, the Scopus database is easy to navigate even for novice users (Burnham, 2006) and is considered as one of the widest coverage journal ranges (Falagas et al., 2008; Ahmi & Mohamad, 2019). This study used the following queries: (TITLE(halal consumption) OR TITLE (halal consumer) OR TITLE (halal customer) OR TITLE (halal user) OR TITLE(halal purchaser). The queries were conducted in July 2020. The words 'consumption', 'consumer', 'customer', 'user', 'purchaser', 'buyer', and 'consume' were grounded in the same discussions on halal, for instance, management issues, corporate product, certification, and authentication. Many studies have considered these aspects of halal to offer potential benefits to consumerism even though their main contribution is in fields other than business and society research. In these cases, it is difficult to draw a line on what is involved in halal consumers and vice versa. For this reason, this study did not conduct a separate search on terms relating to the halal consumer. The flowchart that explains the data collection process is depicted in Figure 1.

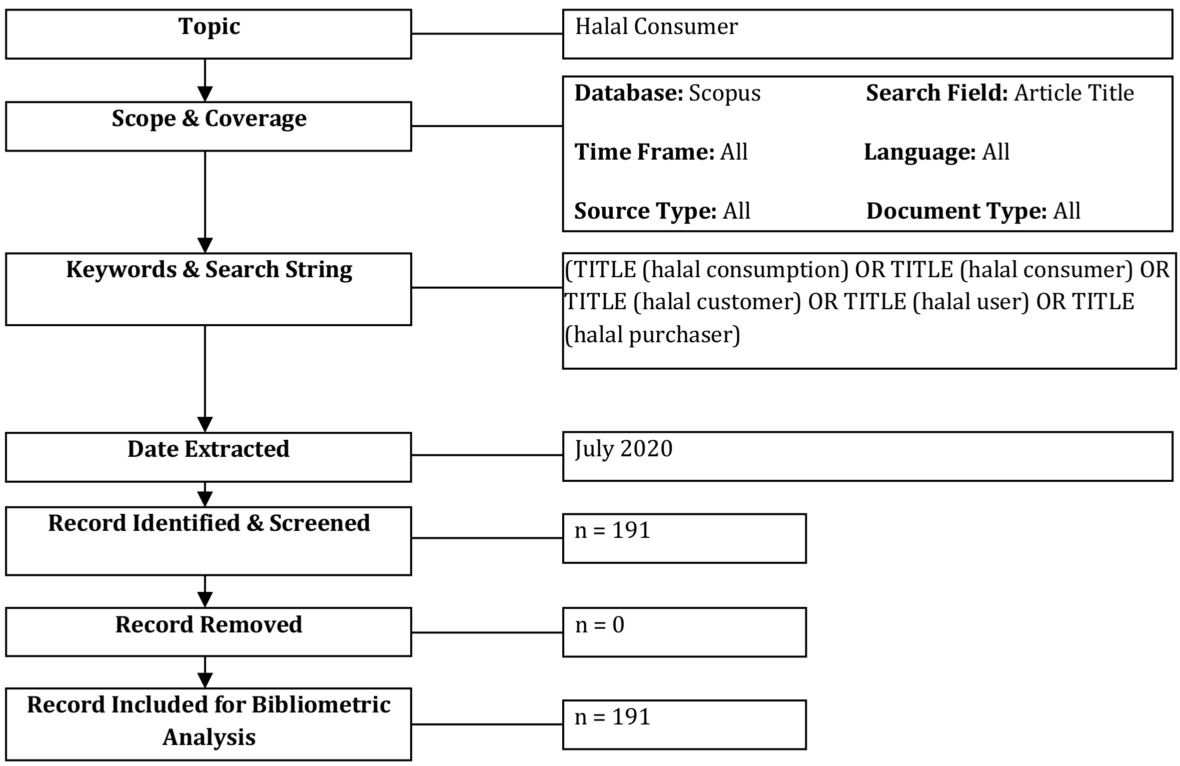

Figure 1. Flow diagram of the search strategy

In the end, this study ended up with a total of 191 academic contributions, including journal articles, conference papers, reviews, book, book chapters, short surveys, and notes. These academic contributions are grouped in Table 1.

Table 1. Academic contributions

Types of Documents	Total Publications (TP)	Percentage (%)
Journal Article	158	82.72
Conference Paper	17	8.90
Review	7	3.66
Book Chapter	5	2.62
Short Survey	2	1.05
Book	1	0.52
Note	1	0.52
Total	**191**	**100.00**

Scopus originated from in Europe (Falagas et al., 2008); therefore, the contributions are dominated by English, which is the most commonly spoken language in the world. Although halal represents the Islamic laws that govern every aspect of individual life, and the concept was first introduced by Muslim countries in their local languages, Table 2 reveals that the practice of local languages is less common for the specialization on halal consumer in the database. This situation might be due to the topic 'consumer' itself which is global; hence, the principles of modern and traditional consumers that are influenced by the view of Western writers (McCracken, 1987; Hernandez & Minor, 2010; Ardoin & Prinyawiwatkul, 2021).

Table 2. The use of languages for publications

Language	Total Publications	Percentage (%)
English	187	97.91
German	1	0.52
Italian	1	0.52
Serbian	1	0.52
Turkish	1	0.52
Total	**191**	**100.00**

Literature analysis through bibliometric tools is proven powerful for identifying established and emerging clusters of research (Fahimnia et al., 2015). Many researchers use bibliometrics to study the performance and impact of journals (Hall, 2011; Donthu et al., 2020) and the scholarly production of the subject domain (Ellegaard & Wallin, 2015), including the halal discipline (Wahyuni et al., 2019; Yagmur et al., 2019; Haleem et al., 2020; Mostafa, 2020). The discussions on the concept of 'halal consumer' using bibliometric analysis were varied, with the majority focusing on tourism, food safety, and supply chain, but none of them reflected on the aquaculture industry.

Results

The findings in this study show that the largest percentage of contributions from halal consumers was via journals compared to other avenues (87.43%) and the journal rank. Based on the most active source title, the arrangement is as follows: Journal of Islamic Marketing, British Food Journal, International Journal of Supply Chain Management, Journal of Food Products Marketing, Advanced Science Letters, Journal of International Food and Agribusiness Marketing, International Food Research Journal, International Journal of Psychosocial Rehabilitation, Meat Science, and Pertanika Journal of Social Sciences and Humanities.

Table 3 shows the trend in the number of published articles. Although the halal consumer field is still in its early growth and expansion period from 2005 to 2009, the result shows a significant growth in the publication from 2011 onwards. As seen in Figure 2, the highest number of publications was in 2019, and it is expected that 2020 will double the amount from what can be seen in July 2019.

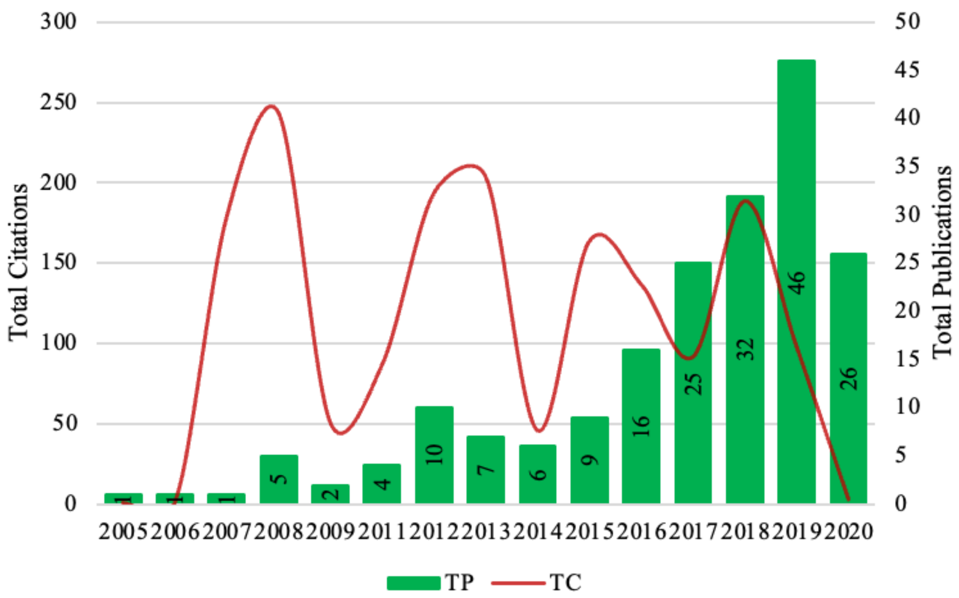

Figure 2. Publication by year (2005 – 2020)

Based on Table 3, although halal consumer publication reached its peak in 2019, the highest average citations per cited publication were found in the publication year of 2007, followed by 2008. The statistic means that halal consumer research gained attention after two years after its first publication in 2005. Meanwhile, the average citations per publication show that 2019 received the lowest value after 2005 and 2006. The average citations per publication started to decrease since in 2015.

Table 3. Year of publications

Year	TP	%	Cumm. %	NCP	TC	C/P	C/CP	h	g
2005	1	0.52	0.52	1	1	1.00	1.00	1	1
2006	1	0.52	1.05	1	1	1.00	1.00	1	1
2007	1	0.52	1.57	1	179	179.00	179.00	1	1
2008	5	2.62	4.19	5	244	48.80	48.80	4	5
2009	2	1.05	5.24	2	51	25.50	25.50	2	2
2011	4	2.09	7.33	3	87	21.75	29.00	3	4
2012	10	5.24	12.57	7	194	19.40	27.71	5	10
2013	7	3.66	16.23	7	204	29.14	29.14	5	7
2014	6	3.14	19.37	5	46	7.67	9.20	3	6
2015	9	4.71	24.08	6	164	18.22	27.33	4	9
2016	16	8.38	32.46	12	137	8.56	11.42	6	11
2017	25	13.09	45.55	17	92	3.68	5.41	6	8
2018	32	16.75	62.30	23	189	5.91	8.22	8	13
2019	46	24.08	86.39	23	98	2.13	4.26	6	8
2020	26	13.61	100.00	3	3	0.12	1.00	1	1
Total	**191**	**100.00**		**116**	**1690**	**8.85**	**14.57**	**22**	**37**

Notes: TP = total number of publications; NCP = number of cited publications; TC = total citations; C/P = average citations per publication; C/CP = average citations per cited publication; h = h-index; and g = g-index.

Table 4 shows 25 subject areas of the halal consumer. The most popular areas are business, management, and accounting, followed by agricultural and biological sciences. Biochemistry, mathematics, physics, pharmaceutics, and chemistry are the least subject areas. The most active source titles (journal) for the subject areas are Journal of Islamic Marketing with 38 publications, followed by British Food Journal (9 publications), International Journal of Supply Chain Management (7 publications), Journal of Food Products Marketing (7 publications), Advanced Science Letters (6 publications), and Journal of International Food and Agribusiness Marketing (5 publications).

Table 4. Subject areas of halal consumer

Subject Areas	Total Publications (TP)	Percentage (%)
Business, Management, and Accounting	102	53.40
Agricultural and Biological Sciences	48	25.13
Social Sciences	32	16.75
Computer Science	28	14.66
Engineering	25	13.09

Table 4. Continued

Subject Areas	Total Publications (TP)	Percentage (%)
Economics, Econometrics, and Finance	23	12.04
Arts and Humanities	18	9.42
Decision Sciences	12	6.28
Environmental Science	11	5.76
Biochemistry, Genetics, and Molecular Biology	9	4.71
Energy	8	4.19
Mathematics	8	4.19
Medicine	8	4.19
Nursing	6	3.14
Physics and Astronomy	4	2.09
Psychology	4	2.09
Materials Science	3	1.57
Veterinary	3	1.57
Chemical Engineering	2	1.05
Multidisciplinary	2	1.05
Pharmacology, Toxicology, and Pharmaceutics	2	1.05
Chemistry	1	0.52
Earth and Planetary Sciences	1	0.52

An analysis of the authors' keywords found that 'halal', 'Malaysia', 'halal food', 'Muslim consumers', 'religiosity', 'consumer', 'attitude', 'halal certification', 'Islam', and 'food quality' were the most frequently used keywords. These keywords are visualized in Figure 3.

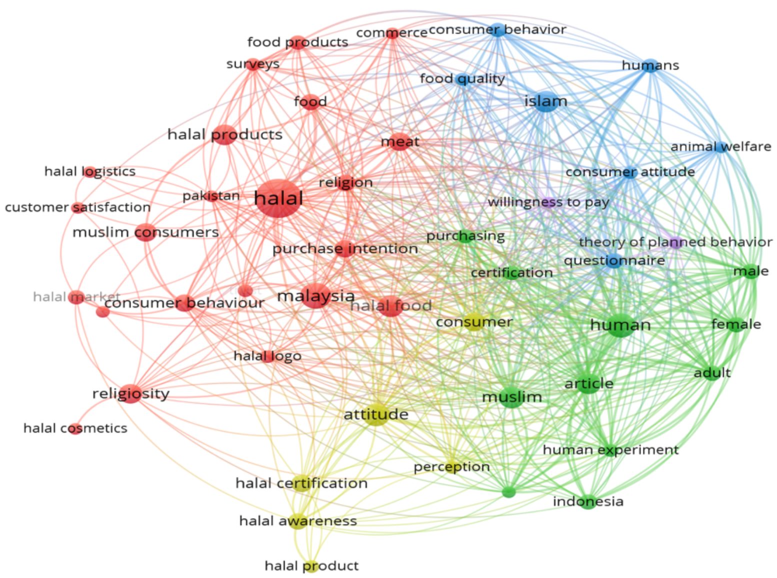

Figure 3. Network visualisation map of the authors' keywords

Table 5 shows the 231 keywords listed by the author. After 'halal', 'Malaysia' was the second most popular keyword. It obtained almost 10% within the two decades of halal consumer research. Keywords such as 'consumer', 'Muslim consumers', 'consumer behaviour' and 'halal certification' were the least searched keywords.

Table 5. Top keywords

Authors' Keywords	Total Publications (TP)	Percentage (%)
Halal	37	19.37
Malaysia	19	9.95
Human	17	8.90
Attitude	15	7.85
Halal Food	14	7.33
Islam	14	7.33
Muslim	14	7.33
Article	13	6.81
Halal Products	13	6.81
Religiosity	12	6.28
Consumer	11	5.76
Meat	11	5.76
Muslim Consumers	11	5.76
Consumer Behaviour	10	5.24
Halal Certification	10	5.24
Purchase Intention	10	5.24

As shown in Figure 4, after Malaysia, the top Asian countries that contributed to most publications are Indonesia and Pakistan. Then, it is followed by non-Muslim countries, such as the United Kingdom, China, and South Korea. However, the United Arab Emirates, which is a Muslim country that uses Arabic as their official speaking language, ranked seventh in the list.

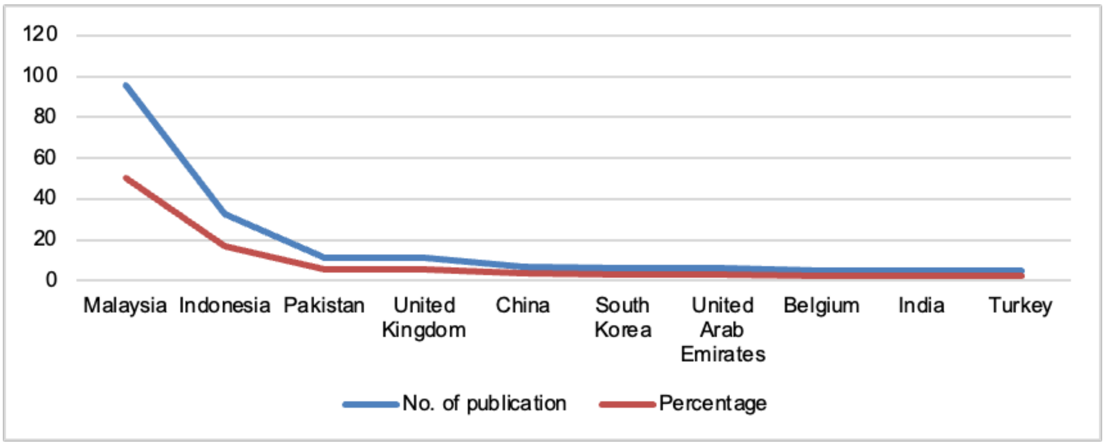

Figure 4. Top countries with five and more publications

Table 6 shows that Universiti Teknologi MARA, Universiti Putra Malaysia, Universiti Utara Malaysia, Universiti Kebangsaan Malaysia, University Malaya, Universiti Sains Malaysia, Universiti Teknologi Malaysia, International Islamic University Malaysia, and Universiti Malaysia Sabah were among the most influential institutions with a minimum of five publications from 2005 to 2020. On the other hand, Hogeschool Gent and Universiteit Gent, both from Belgium, were the only non-Malaysian institutions.

Table 6. Most influential institutions with a minimum of five publications

Institution	Country	TP	%
Universiti Teknologi MARA	Malaysia	21	10.99
Universiti Putra Malaysia	Malaysia	15	7.85
Universiti Utara Malaysia	Malaysia	12	6.28
Universiti Kebangsaan Malaysia	Malaysia	11	5.76
University Malaya	Malaysia	11	5.76
Universiti Sains Malaysia	Malaysia	8	4.19
Universiti Teknologi Malaysia	Malaysia	7	3.66
International Islamic University	Malaysia	6	3.14
Hogeschool Gent	Belgium	5	2.62
Universiti Malaysia Sabah	Malaysia	5	2.62
Universiteit Gent	Belgium	5	2.62

Notes: TP = total number of publications; % = percentage

Discussion

This article provides several insights into the questions posed in the earlier section: (1) what are the characteristics of the literature produced in halal consumer since the early 2000s in terms of type, influence, and impact? (2) what are the influence and productivity levels of researchers within the halal consumer research community and institutions? and (3) how would the halal consumer research shape the aquaculture field?

First, the years 2007 and 2015 witnessed different patterns of average citations per publication. The latter, unlike the former, was found to act as a starting year for low average citations per publication. Since its first publication in 2005, halal consumer research has shown a decrease in citations after ten years. In our opinion, this is a good sign for researchers to start studying other fields of studies such as aquaculture to work with halal consumers. The year 2020 onwards should be characterized by other fields that are positively correlated with the human population's size and growth rate. Food and Agricultural Organisation (FAO) of the United Nations (2018) stated: "aquaculture contributes over 15% of animal proteins in human consumption and thus plays an essential role in eradicating poverty and achieving sustainable development worldwide by 2030."

Second, the bibliometric analysis reveals that business, management, and accounting were the most influential subject areas, with more than 50% contributions to the halal consumer field. However, we doubted that this could be a good sign for halal consumer research, especially in the long run. We have a different understanding of what the figures imply. We see that 50% means that business, management, and accounting are the most 'matured' fields in halal consumer research nowadays. Agricultural and biological sciences were the second most influential subject area in halal consumer research. According to Chengwei Liu from the Warwick Business School, "finishing in second place could make you the real winner in the long run" (Hosie, 2017).

Third, the bibliometric analysis exposes the three most active source titles (journals) with the word 'food': British Food Journal, Journal of Food Products Marketing, and Journal of International Food and Agribusiness Marketing. The literature shows that agriculture and food are interrelated with each other. Both fields share the same issues as follows: climate change (Kogo et al., 2021), innovation for life (Gremmen et al., 2019), and improved nutrition (Saravanakumar et al., 2020). According to Little et al. (2016), aquaculture is a rapidly growing sector of food in agriculture. This is because aquaculture, specifically the farming of aquatic animals, has expanded faster in recent decades than other livestock sectors.

Finally, the bibliometric analysis shows that 9 of the 11 most influential institutions in halal consumer research are from Malaysia. The second top keyword is also 'Malaysia'. It is quoted that the agricultural sector has played an important role in the economic growth of Malaysia. The sector is expected to contribute 3.5% of Gross Domestic Product (GDP) in the Eleventh Malaysia Plan (2016–2020). For the financial year 2016, the Federal Government has approved an allocation grant of RM169.77 million. The government's concern in helping to reduce the cost of living of fishermen was continued through the Fisheries Development Authority of Malaysia (FDAM) through the Fishermen Living Allowance Program (ESHN) and the Program of Incentives for Fishing Products (IHTN). It is clear from all these facts and figures that halal consumer researchers have a great opportunity to venture into the aquaculture discipline

Conclusion

This article has established a new area of halal consumer-aquaculture research from the bibliometric analysis. It is hoped that this study can be used to reflect the direction of future halal consumer research. We believe that business, management, and accounting scholars focus on aquaculture disciplines and realize that the key to defining aquaculture in halal consumers is promising.

Researchers over the world share the responsibility to ensure the conduct of high-quality, scientifically rigorous, and ethically sound research of halal consumers. This study found that halal consumer research has steadily created its field as promising for about two decades; hence, researchers should take the opportunity to benefit from multi-discipline research participation.

Freshwater aquaculture such as catfish, carp, red tilapia, black tilapia, snakehead, and prawn can be the main sources of protein supply in Malaysia because they have the potential to grow further. However, there are very limited empirical studies on halal and fisheries in Malaysia. This study sees as a big opportunity for halal researchers especially when the study of health supplements in Malaysia (Zakuan & Ismail, 2019) and organic food consumption in response to the COVID-19 pandemic is also increasing and predicted to grow enormously (Latip et al., 2020).

Halal consumer research is designed mostly according to business, management, and accounting disciplines. The word 'halal consumer' is the sign of 'product', 'purchase', and 'certification', which were depicted as the top authors' keywords. However, there is significant evidence from the findings, especially from the year 2019 onwards, that the utilized channel of deployed business, management, and accounting is approaching its maximum limit.

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Supplementation of *Kappaphycus alvarezii* Solid Waste (Bioethanol Production) in Fish Feed for *Barbonymus schwanenfeldii* Growth

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Abstract

Kappaphycus alvarezii is a renewable resource rich in dietary sources such as vitamins, proteins, carbohydrates and trace minerals. The solid waste of this marine macroalgae produced from bioethanol production was used to produce fish feed. This study aims to evaluate the efficacy of *K. alvarezii* fish feed in *Barbonymus schwanenfeldii* fish growth. The proximate analysis, micro and macronutrient and mycotoxin in the *K. alvarezii* fish feed were determined using a standard protocol. For the fish culture design, fish were randomly divided into two groups: group I – feed with commercial fish feed (control); group II – feed with *K. alvarezii* fish feed (experimental group). The initial body weight of the fish was recorded, and thereafter weekly for 12 weeks. Proximate analysis indicated that the dried *K. alvarezii* fish feed is high in nitrogen (46.30±0.1%) and low in moisture (6.40±0.1%), ash (4.50±0.1%) and fiber (4.75±0.1%) contents, while rich in macro and micronutrients. There was no mycotoxin found in the *K. alvarezii* fish feed. For the 12 weeks of the feeding of commercial and *K. alvarezii* fish feed, our results did not show any significant difference ($P > 0.05$) in the *B. schwanenfeldii* specific growth rate between the groups, 0.36±0.03% in the control group and 0.34±0.02% in the experimental group, respectively. Proximate analysis of the *B. schwanenfeldii* fish, indicated a moisture content of 19.20±0.1%, crude extract protein of 74.70±0.1% and crude lipid of 3.50±0.1% in the control group, which are significantly higher ($P < 0.05$) than in the experimental group [moisture content (15.60±0.1%), crude extract protein (70.00±0.1%) and crude lipid (2.60±0.1%)]. Although the proximate analysis in the control group is significantly higher than the experimental group, the use of *K. alvarezii* as fish feed supplement is still a good option as it utilizes the waste of *K. alvarezii* and can support towards the UN Sustainable Development Goal 12, Responsible Consumption and Production.

Keywords: *Kappaphycus alvarezii*, fish feed production, fish feed supplement, *Barbonymus schwanenfeldii*, UN SDG12

Introduction

By the year 2050, it is predicted that food production will increase by 60% to fulfil the growing human population (United Nations, 2007). Global issues such as increasing environmental conflict, limited freshwater supply, decreasing arable lands and changing eating patterns were causing food production to drop (Tacon, 1987; Duarte et al., 2009). Increasing market demand for meat and dairy products has also increased the demand for animal feed. Therefore, animal feed is leading the global food industry, enabling economic growth (FAO, 2010). Recently, the world has increased its interest in exploring the possibility of using seaweed in animal feed due to its nutrients (Lum et al., 2013).

In 2013, the total feed production in the world was estimated at 963 million tonnes which was 9 million tonnes higher than the previous year. Asia contributed the most, 348 million tonnes, followed by Europe with 227 million tonnes and North America with 189 million tonnes. The increasing production shows the increased interest in the market towards the available feeds that have health benefits to the livestock.

Seaweed is a sustainable and renewable resource as nutrient-rich food with a high growth rate. Cultivating seaweed does not require fertilizers, pesticides and freshwater and only requires one-sixth of the surface needed by plants. About 6000 species of seaweed can be found on earth, but only 5% of them are used as food for humans or animals (Chojnacka et al., 2012). Traditionally, seaweed is used as food, feed, fuel, medicine and cosmetics due to its nutraceutical value and biochemical composition. In recent, there are scientific research shows the positive effects of seaweed on human and animal health.

Seaweeds are good dietary sources high in vitamins, proteins, carbohydrates, and trace minerals (Kumar et al., 2008). Besides, seaweed is also found to be low in lipid and high in polysaccharides and bioactive molecules. As a nutrient-rich agriculture product, seaweed can improve gastrointestinal flora, improve immunity, enhance growth performance, and increase milk and meat quality and yield in livestock (Carrillo et al., 2008; Bendary et al., 2013). Furthermore, a seaweed-based diet for aquaculture improved weight gain, increased triglyceride and protein in muscle, improved resistance to disease and less mortality, better growth index, higher gutted weight, increased fish digestibility, enhanced natural pigmentation, carcass quality and starvation tolerance and decreased nitrogen output into the environment (Becker et al., 2007; Fleurence et al., 2012).

Therefore, seaweed could be a good source of nutrient supply. Seaweed is abundantly used as dietary supplementation in the aquaculture Fields (Hashim & Saat, 1992; Cruz-Suárez et al., 2000; Valente et al., 2006). Generally, seaweed is divided into three types; red seaweed, green seaweed and brown seaweed (Guiry & Guiry, 2016). *Kappaphycus alvarezii* is a type of red seaweed which is abundantly found in the Indo-Pacific region spreading from the area of eastern Africa to

Guam, and it is most concentrated in the Southeast Asian Region. In Malaysia, *K. alvarezii* is abundantly cultivated in Sabah state (Trono, 1992).

Fish is a good protein source for human usage because it provides high-quality protein for people (Tidwell & Allan, 2001). Besides, the demand for fish is also increasing from 151 thousand tonnes in 2000 to 202 thousand tonnes in 2016 in Malaysia. Fish feed is the main component of growing aquaculture production, where the feed influences the growth and quality of the fish (Pereira et al., 2012). Fish feed generally consists of proteins, amino acids, carbohydrates, lipids, energy, minerals and vitamins. Fish requires the balance of nutrients in the feed for growth, energy and reproduction.

Barbonymus schwanenfeldii is a freshwater fish found in Southeast Asia, such as the Mekong river, Sumatera, Borneo and Peninsular Malaysia (Christensen, 1992). The species is classified as an omnivore, where it consumes both meaty and plant-based foods. It consumes smaller fish, small invertebrates and aquatic plants in the wild. An adult *B. schwanenfeldii* could grow up to approximately 35.5 cm total length. The optimal water conditions for *B. schwanenfeldii* are pH 6.0 to 7.5 and temperature 20.4 to 33.7^{0}C. This study is aimed at evaluating the efficacy of fish feed produced from *K. alvarezii* solid waste in the freshwater fish species *B. schwanenfeldii*.

Materials and Methods

Sample preparation

Solid wastes of *Kappaphycus alvarezii* from bioethanol production (acid hydrolysis) was collected and washed with distilled water. The *K. alvarezii* solid waste was dried and weighed until a constant weight was obtained. The dried *K. alvarezii* solid waste was stored at -20°C until further use.

Fish feed preparation

The fish feed formulation was made with proteins of vegetable origin, mainly soybean meal. The list of the ingredients is expressed in weight (kg), as shown in Table 1. Only 3% *K. alvarezii* solid waste was included in the fish feed production. of the dry ingredients were weighed and mixed homogeneously. The soybean oil was added to the mixture and mixed thoroughly for 5 minutes. Water was added to the mixture, and a soft but non-sticky dough was obtained. The dough was steamed cooked for 15 minutes until gelatinization and then shaped into the desired pellet size (0.4+0.1cm) using the meat mincer. The pellets were dried at 75°C for 45 minutes before storing in an airtight plastic container.

Table 1. Recipe for a 10 kg-fish feed using plant-based protein

Feed ingredient	Weight (kg)	Percentage of total feed (%)
Corn meal	1.0	10
Wheat flour	1.0	10
Soybean meal	6.7	67
soybean oil	0.2	2
Wheat bran	0.7	7
K. alvarezii solid waste	0.3	3
Total amount	**10.0**	**100**

Proximate Analysis of Fish Feed and Fish Samples

Moisture content determination

The sample's moisture content was determined by the weight loss of the sample when it was dried to a constant weight in an oven (Bhuiyan et al., 2016). The sample's initial weight was recorded and placed in an oven at 90^{0}C for 24 hours. The sample was cold and weighted. The drying and weighing continue until a constant weight is obtained. The moisture content can be calculated by the formula below:

$$\text{Moisture content (\%)} = \frac{initial\ sample\ weight - final\ sample\ weight}{initial\ sample\ weight} \times 100\%$$

Ash content determination

The initial weight of the sample was obtained. The sample was placed into the ashing furnace at 600□C for 4 hours until the whitish-grey ash was obtained (Bhuiyan et al. 2016). The remaining ash was cool and weight. The following formula can calculate the ash content:

$$\text{Ash content (\%)} = \frac{weight\ of\ ash}{initial\ weight\ of\ sample} \times 100\%$$

Crude protein determination

Crude protein was determined by the Kjeldahl method. The sample was first digested using concentrated sulphuric acid, copper sulphate, sodium sulphate and a speck of selenium tablet until the digest became pale green. The mixture was left completely cold, and distilled water was added. The digest was undergoing distillation; sodium hydroxide was added to the marshal distillation apparatus and allowed to boil. The mixture was distilled into 2% boric acid containing screened methyl red indicator. In the end, the alkaline ammonium borate formed was titrated directly with 0.1N HCl. The titre value of the acid used was recorded, and the crude protein was calculated by the formula below:

$$N\,(\%) = \frac{14 \times VA \times 0.1 \times w}{1000 \times 100} \times 100$$

VA = volume of acid used; w = weight of the sample

Crude protein (%) = N (%) x 6.25

Crude lipid determination

Extraction of ether was carried out by mixing the sample with anhydrous diethyl ether and the mixture was boiled for 4 hours (adopted from Bhuiyan et al., 2016 with modification). After the extraction, the sample was dried at 65℃ for 4 hours. The sample was allowed to cold and weighted.

$$\text{Crude lipid } (\%) = \frac{weight\ of\ extract}{weight\ of\ initial\ sample} \times 100\%$$

Crude fiber determination

The fat-free sample from ether extraction was used to determine the crude fiber in the sample (modified from Oladipo & Bankole, 2013). The fat-free sample was added to pre-heated 1.25% H_2SO_4 and boiled for 30 minutes. The sample was filtered and washed with hot water and ethanol. The residue was dried at 65℃ for 24 hours. The cooled sample was weighed and recorded. The residue was ashed in a muffle furnace at 600℃ for 4 hours. The ash was cooled and weighed.

$$\text{Crude fiber } (\%) = \frac{dry\ weight\ of\ residue\ before\ ashing - weight\ of\ residue\ after\ ashing}{weight\ of\ sample} \times 100$$

Nitrogen-free extract (NPE) determination

Nitrogen content in the sample was determined by subtracting the percentage of all the nutrients already determined from 100 (Bhaskar et al. 2015).

$$\text{NPE } (\%) = 100 - [Moisture\ content\ (\%) + Crude\ fiber\ (\%) + Crude\ protein\ (\%)\ Crude\ lipid\ (\%) + Ash\ (\%)]$$

Mycotoxin determination in a fish feed sample

The fish feed sample was ground into powder. The mycotoxins in fish feed were extracted with 10mL methyl cyanide (MeCN) containing 2% formic acid. The mixture was then centrifuged, and the supernatant was obtained. The sample was then purified, and the solvent was exchanged with MeOH: H_2O (50:50, v/v). For mycotoxins quantification, 10µL of the sample was injected into the

HPLC column, which was heated to 45□C. 10mM ammonium formate and MeOH were used as mobile phases with a flow rate of 300□L/min. The sample was run for 21 minutes (including 5 minutes of equilibration). The mycotoxin determination method was adapted from the Association of Official Analytical Chemists (AOAC) official method 991.31. The tested parameters are aflatoxin (B1, B2, G1, G2), deoxynivalenol (DON), zearalenone, t-2 Toxin, fumonisins (B1, B2) and ochratoxin A. All the test parameters were expressed in ppb.

Macro and micronutrients in K. alvarezii fish feed

The macro and micronutrients in *K. alvarezii* fish feed were carried out using the Association of Official Analytical Chemists (AOAC) official method 999.11. AOAC standard analytical methods are used to analyze different sources, including fertilizers, food and waste related to agriculture and the environment. The macro and micronutrients are phosphorus, potassium, calcium, sulfur, magnesium, chloride, manganese, iron, zinc and copper. All the test parameters were expressed in ppm.

Culture tank design and set up

The aquaculture system consists of a fish tank and a settling tank. Water from the fish tank was directed to a settling tank to remove all the solid waste produced from the fish and food. The settling tank consisted of a pump, a biofilter and a compartment for filtered water. The recirculating water system was operated for 12 weeks with 9 hours light/15 hours dark.

Thirty *B. schwanenfeldii* fish (≈20g) was randomly divided into two groups: group I – feed with commercial fish feed (control); group II – feed with *K. alvarezii* fish feed (experimental group). All the fishes were fed twice per day (0900 and 1600), and the following equation determined the feeding amount:

Amount of feed = average fish weight (g) x 5% of fish weight x total number of fish

The body weight of *B. schwanenfeldii* fish was measured weekly. At 12th week, the fish starved for 24 hours, and sacrificed by chilling on ice. The *B. schwanenfeldii* carcasses were stored at -80□C for further usage.

The final body weight of *B. schwanenfeldii* fish was measured. The specific growth rate (SGR) was calculated according to the following equation:

$$\text{SGR (\% body wt. gain/day)} = \frac{Log(final\ weight) - Log(initial\ weight)}{t} \times 100\%$$

Water parameters in an aquaculture system

Water parameters in the aquaculture tank were determined using LAQUA Twin Compact Meters (pH, temperature, ammonia, nitrite and nitrate) and a dissolved oxygen meter weekly. All the test parameters were expressed in ppm.

Microbe on the B. schwanenfeldii

B. schwanenfeldii fish were harvested and undergoing microbe examination. For microbe examination, aerobic plate counts (AOAC official method 990.12), yeast (AOAC official method 2014.05), mould (AOAC official method 2014.05), coliform (AOAC official method 990.08 & 991.14), *E. coli* coliform (AOAC official method 990.08 & 991.14), *Staphylococcus aureus* (AOAC official method 2003.11, 2003.07 & 2003.08) and salmonella (AOAC official method 2014.01) were examined. The samples were examined by using the AOAC official method accordingly.

Results

Proximate analysis of K. alvarezii fish feed

Proximate analysis was carried out for the *K. alvarezii* fish feed sample (dry). The fish feed sample is found to be high in nitrogen content and low in moisture, ash and fiber content. The proximate analysis for *K. alvarezii* fish feed is shown in Table 2.

Table 2. Proximate analysis of *K. alvarezii* fish feed

Parameters	***K. alvarezii* fish feed** (mean□SD %)
Moisture content	6.40□0.1
Ash	4.50□0.1
Crude protein	27.00□0.1
Crude lipid	11.10□0.2
Crude fiber	4.75□0.1
Nitrogen free extract	46.30□0.1

Mycotoxin in fish feed

Mycotoxin in fish feed was carried out. The tested mycotoxins are Aflatoxin (B1, B2, G1, G2), deoxynivalenol (DON), zearalenone, t-2 Toxin, fumonisins (B1, B2) and ochratoxin A. None of the tested mycotoxins was found in the fish feed sample. The mycotoxin in fish feed is shown in Table 3.

Table 3. Mycotoxin in fish feed

Test parameters	Unit	Reading
Aflatoxin (B1, B2, G1, G2)	ppb	ND (< 0.1)
Dexoynivalenol (DON)	ppb	ND (< 5)
Zearalenone	ppb	ND (< 10)
t-2 Toxin	ppb	ND (< 5)
Fumonisins (B1, B2)	ppb	ND (< 50)
Ochratoxin A	ppb	ND (< 0.5)

Value are mean□SD. ND denotes not detected.

The *K. alvarezii* solid wastes are rich in phosphorus, potassium, calcium and sulfur. The macro and micronutrients in *K. alvarezii* solid waste is shown in Table 4.

Table 4. The macro and micronutrients in *K. alvarezii* solid waste

Test parameters	Reading
Phosphorus	404.3□0.14 ppm
Potassium	1230.0□0.07 ppm
Calcium	969.0□0.42 ppm
Sulfur	4692.7□66.26 ppm
Magnesium	297.0□0.07 ppm
Chloride	207.2□0.14 ppm
Manganese	2.4□0.02 ppm
Iron	50.2□0..01 ppm
Zinc	9.56□0.03 ppm
Copper	11.96□0.02 ppm

Value are mean□SD. ND denotes not detected.

The specific growth rate of B. schwanenfeldii fish

The specific growth rates for *B. schwanenfeldii* fish in the control and experimental group were not significantly different ($P > 0.05$). However, no significance was found between the groups but the specific growth rate in control group is relatively higher than the specific growth rate in the experimental group. The specific growth rate for *B. schwanenfeldii* fish in the control and experimental group is shown in Table 5.

Table 5. Specific growth rate between the control group and experimental group

Group	Specific growth rate (%)
Control group	0.36±0.03^{a}
Experimental group	0.34±0.02^{a}

Values are mean±SD. Different superscript letters in each row indicate a statistical significantly different at $P < 0.05$.

Proximate analysis of B. schwanenfeldii fish in the control and experimental group.

Proximate analysis of *B. schwanenfeldii* fish in control and experimental groups was carried out. Moisture content, ash, crude protein and fat in the *B. schwanenfeldii* fish were measured. The proximate analysis for the *B. schwanenfeldii* fish is shown in Table 6.

Table 6. Proximate analysis of *B. schwanenfeldii* fish for the control and experimental groups

Parameters	Control group	Experimental group
Moisture content	19.20±0.1^{a}	15.60±0.1^{b}
Ash	7.00±0.2^{a}	10.50±0.2^{b}
Crude protein	74.70±0.1^{a}	70.00±0.1^{b}
Crude lipid	3.5±0.1^{a}	2.60±0.1^{b}

Values are mean±SD. Different superscript letters in each row indicate a statistical significantly different at $P < 0.05$.

Water parameters in an aquaculture system

For the 12 weeks of study, the water quality of the aquaculture was maintained at pH (7.25±0.10), temperature (24.10±0.21°C), DO (6.51±0.03ppm), ammonia (0.00ppm), nitrite(0.00ppm) and nitrate (59.42±3.12ppm).

Microbiology tests on the B. schwanenfeldii fish

For the microbiology test on *B. schwanenfeldii* fish, aerobic plate counts, yeast, mould, coliform, *E. coli*, *Staphylococcus aureus*, and *salmonella* were tested. Results of the microbiology examination of *B. schwanenfeldii* fish is shown in Table 7.

Table 7. Microbiological test on *B. schwanenfeldii* fish

Microbes	Reading
Aerobic plate counts	1.3×10^{4} (35°C, CFU/g)
Yeast	20 (25°C, CFU/g)
Mould	90 (35°C, CFU/g)
Coliform	40 (35°C, CFU/g)

Table 7. Continued

Microbes	Reading
E. coli	ND
Staphylococcus aureus	ND
Salmonella	ND

ND denotes not detected.

Discussion

Moisture content in the feed is a common property of food materials, and it is important to ensure feed quality and stability. The moisture content in *K. alvarezii* fish feed is 6.40±0.1%, and the suggested moisture content is usually less than 10%. Thus, the moisture content in the *K. alvarezii* fish feed fits the standard. The moisture content in the feed will interfere with the microbial stability where the tendency of microorganisms to grow in the feed relies on the water container. Besides, the fish feed quality, such as texture, taste and stability, also depends on the water contained. Furthermore, the feed's moisture content impacts feed intake and nutrient utilization of the animal (Oehme et al., 2014).

The growth performance of the fishes is dependent on the feed nutrients. Thus the correct balance of proteins, carbohydrates, fats, vitamins and minerals is required for the fish to grow and be healthy. The crude protein in the *K. alvarezii* fish feed is 27.00±0.1%. Protein is the most important component in the fish feed, which helps to build up the fish mass. Omnivorous fish such as *B. schwanenfeldii* need around 25 to 35% of their diet's protein to grow at optimal levels. Proteins are built by different amino acids to form other structures and enzymes in living organisms (Gatlin, 2010). Therefore, *K. alvarezii* fish feed would supply a good source of protein for the *B. schwanenfeldii*.

Ash content represents the total mineral content in the feed, and the mineral content such as Ca, Na, K and Cl are the specific inorganic components present. The ash content in *K. alvarezii* fish feed is 4.50±0.1%. Generally, the feed's ash content is approximately 5% (Hoffman, 1993). The ash content in feed correlated with the quality, microbiology stability and nutrition in the fish feed. High mineral content in the feed can be used to prohibit the growth of certain microorganisms, and the mineral elements such as Ca, P, K, and Na are needed for the fishes to grow in a healthy (Shearer et al., 1992; Cai-Juan et al., 2016).

Furthermore, lipid nutrition in fish feed is essential to supply essential fatty acids such as long chain polysaturated fatty acids (PUFA), -Linolenic Acid (LNA, 18:3ω3), Linoleic Acid (LA, 18:2ω6), eicosapentaenoic acid (EPA, 20:5ω3) and docosahexaenoic acid (DHA, 22:6ω3). In this study, fatty acid experiments were not included. The crude lipid content in *K. alvarezii* fish feed is 11.10±0.2%, whereas the suggested lipid content in fish feed is 10 to 15%. Dietary lipid is needed for membrane structural components and acts as precursors of steroid hormones and prostaglandins in fish (Craig & Helfrich, 2002; Hixson, 2014).

There are various sizes and complexity of carbohydrates that are reduced by plants reduces. Inexpensive carbohydrates are used as an energy source for the fish. The crude fiber content in *K. alvarezii* fish feed is 4.75□0.1%, and the general fish feed content is usually less than 7%. This is because fish cannot digest high content of crude fiber; thus, the crude fiber must be kept at a very low-level (Gatlin, 2010). The nitrogen-free extract in *K. alvarezii* fish feed is 46.30□0.1%, where the nitrogen-free extract is made up of carbohydrates such as sugars and starches. It usually contained 25 to 45% in fish feed to provide good integrity and stability and make the pellet less dense (Dhaneesh et al., 2012).

Mineral elements in fish feed are essential for tissue formation, osmoregulation and metabolic functions. *K. alvarezii* solid waste is rich in calcium, phosphorus, magnesium, chloride, potassium and sulfur. The minerals are macro minerals needed in large quantities in the diet and stored in the body. Among the macro minerals, phosphorus is the most critical macro mineral. This is because phosphorus only exists a little in water. Phosphorus is an essential mineral to build up the bone and scales in various biochemical. Besides, chloride and potassium are crucial electrolytes for osmoregulation and acid-base balance in the body. Furthermore, magnesium is needed for intra and extracellular homeostasis and cellular respiration (Tacon, 1987; Warne, 2014; Mohanty et al., 2016). Micro mineral or trace minerals found in *K. alvarezii* solid waste included copper, iodine, iron, manganese and zinc. Micro minerals are needed in low amounts. Although these minerals are required in low doses, they must form a complete diet for the fish to grow.

Mycotoxins are toxic chemicals produced by several species of moulds such as *Aspergillus*, *Penicillium* or *Fusarium* genera. In this study, the *K. alvarezii* fish feed is free from mycotoxin. Mycotoxin is Aflatoxin (B1, B2, G1, G2), deoxynivalenol, zearalenone, t-2 Toxin, fumonisins (B1, B2), and ochratoxin A. Contamination of mycotoxin in fish feed is usually related to the storing method. When the fish feed is exposed to the air with high moisture conditions, it may produce mycotoxin. Ingestion of mycotoxin-contaminated feed might cause the fish to lose weight, immune impairment and organ lesions (Manning, 2010; Anater et al., 2016; Marijani et al., 2017; Matejova et al., 2017). Fish feed is the nutrient source for the fish. Thus, ensuring that the fish feed is free from mycotoxin is essential.

After 60 days of feeding of *K. alvarezii* and commercial feed for experimental and control groups, the specific growth rate for *B. schwanenfeldii* fish in the control and experimental groups is not significantly different. The growth of the *B. schwanenfeldii* fish is highly correlated with the supplemented fish feed. *K. alvarezii* fish feed provides a good source of protein, fat, and macro and micronutrients. It thus can supply sufficient nutrients that are needed by the *B. schwanenfeldii* to grow. Compared to commercial feed fed to the control group, no significant difference was found in the specific growth rate. Therefore, *K. Alvarezii* fish feed is suitable for *B. schwanenfeldii* fish.

Although no significant difference was found in the specific growth rate between the control and experimental groups, there is a significant difference in proximate analysis. According to the commercial fish feed labelling, the proximate analysis for the fish feed is ash (≤ 17%), crude protein (≥ 40%), crude lipid (≥ 9%) and crude fiber (≤ 2%) (Sutharshiny and Sivashanthini 2011; Njinkoue et al. 2016). Compared to *K. alvarezii* fish feed, the commercial fish feed has a higher crude protein and lipid content; thus, it has more protein and fat content for the *B. schwanenfeldii* fish. In Table 5, crude protein and crude lipid in the control group are significantly higher than in the experimental group. Since the commercial fish feed has higher protein and fat content, thus *B. schwanenfeldii* fish in the control group tend to have higher protein and fat content than the experimental group.

Furthermore, the growth of *B. schwanenfeldii* fish also depends on the water quality. *B. schwanenfeldii* is warm water fish that can be found in Southeast Asia. In general, the water quality for warm water fish is suggested to maintain at temperature (22-32□C), DO (4-6ppm), pH (6-8.5), ammonia (< 3ppm), nitrite (< 1ppm) and nitrate (< 400ppm). For temperature, it is correlated with the solubility of gases in water, the reaction rate of chemicals and the toxicity of ammonia to the fish. When the water temperature increases, the solubility of oxygen will decrease. Oxygen is one of the factors for the growth and well-being of fish. Oxygen is needed for fish respiration. At optimal temperature, the DO is around 4 to 6ppm. When the DO in water is less than 4ppm, the fish will stop feeding, growth slows down and stress-related begins. Besides that, the pH value in the water is also crucial for fish health. The fish can die from pH shock resulting from the sudden change of pH in the water. Despite that, the ammonia content in the water is excreted from the fish gills and as urine. Besides, solid waste contributes to the ammonia content in the water. The high ammonia content is toxic to fish, destroying the fish's central nervous system and gills, resulting in impaired respiration and convulsions. The toxicity of ammonia is also correlated with pH and temperature, where at higher pH value and temperature, the ammonia is more toxic to the fish. Ammonia in the water will be nitrified by bacteria and converted into nitrite and nitrate. Nitrite is toxic to the fish, and a high nitrite level may cause the fish to die rapidly. Furthermore, nitrate is less toxic and more tolerable to the fish. The tolerating level of nitrate for the fish is as high as 400ppm (Myrick, 2011; Kasnir et al., 2014; Moffat, 2017). Thus, the water quality in the study was maintained at pH (7.25□0.10), temperature (24.10□0.21□C), DO (6.51□0.03ppm), ammonia (0.00ppm), nitrite(0.00ppm) and nitrate (59.42□3.12ppm).

The microbiological testing for food samples is to ensure food safety. Aerobic plate count, yeast, mould, coliform, *E. coli*, *Staphylococcus aureus* and *Salmonella* are the most common food safety microbiological tests. Aerobic plate count is one of the most common tests used to investigate the microbial quality of the food (Broekaert et al., 2011; Sanjee & Karim, 2016). In general, the microbial quantity should be less than 10^6 CFU/g. The aerobic plate count for the *B. schwanenfeldii* fish sample is 1.3.104 CFU/g which fits the food safety guideline. Yeast and mould are always found in food and water. Existing of this bacteria in food is always correlated with food spoilage. Thus, the microbiological quantity for yeast and mould should always be less than 1000 CFU/g. For *B. schwanenfeldii* fish sample, the yeast (20 CFU/g), Mould (90 CFU/g) are much lower than the limit (van den Broek et al. 1984). Furthermore, coliform is naturally found in the intestines of animals, and the presence of coliform indicates the possibility of being contaminated by the faecal (Varga & Anderson 1968). The contaminant limit for coliform is less than 100 CFU/g, and the coliform found in *B. schwanenfeldii* fish sample is 40 CFU/g (HPA, 2009).

Despite that, the pathogenic bacteria; *E. coli*, *Staphylococcus aureus* and *Salmonella* are absent in the *B. schwanenfeldii* fish sample. *E. coli* is an undesirable bacterial in food, indicating poor hygienic conditions. In nature, *E. coli* should not be found in fish except in grossly polluted waters (Teophilo et al., 2002). Besides, *Staphylococcus aureus* is naturally present in human skin, hair and superficial mucous but not on fish and fish products. The presence of it indicates the presence of enterotoxin and the sanitary or production practice (Simon & Sanjeev, 2007; Saito et al., 2011; Obaidat et al., 2015). Lastly, the presence of Salmonella in food also indicates poor food handling, such as cross-contamination. *Salmonella* can cause fever, diarrhoea, intestinal cramps and vomiting. Thus it is important to eliminate salmonella from the food, especially in the ready-to-eat food (Heinitz et al., 2000; Zhang et al., 2013).

Conclusion

Kappaphycus alvarezii fish feed is rich in macro and micronutrients where it can supply balanced nutrients for the *B. schwanenfeldii* fish. Besides, the *K. alvarezii* fish feed could provide a good source of protein and fat for the *B. schwanenfeldii* fish to grow. Furthermore, the *K. alvarezii* fish feed is free from mycotoxin; thus, it is safe to be consumed by the *B. schwanenfeldii* fish. The specific growth rate for both control and experimental groups was not significantly found. Although the crude protein and fat content in the control group are significantly higher than in the experimental group, K. alvarezii fish feed is still a potential fish feed that could be used to grow *B. schwanenfeldii* fish. Lastly, there are no pathogenic bacteria found in *B. schwanenfeldii* fish. Although a small amount of yeast, mould and coliform were detected, the microbial quantity is within limits.

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Bycatch Estimates of Dugongs and Dolphins: Results from an Interview Survey of Fishermen in Brunei Bay, Malaysia

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Abstract

Bycatch refers to the unintentional capture of non-targeted animals during fishing activities. Worldwide, bycatch poses a significant threat to marine mammal species. In the Southeast Asian region, information on bycatch is particularly scarce, and there is little indication that the issue is adequately addressed anywhere in the region. To address this knowledge gap, we conducted face-to-face interview surveys across fishing communities in the Malaysian side of the Brunei Bay. We collected two datasets of marine mammal bycatch incidences from two different groups of fishermen (N=90 of 356 reported dugong data, 0.3%, and N=62 of 146 reported dolphin data, 0.4%), to estimate the levels of mortalities of the marine mammals. More than four fifths (82.1%) of respondents reported that they have accidentally captured at least one marine mammal (25.0% dugong and 42.5% dolphin) throughout their lifetime as a fisherman, with the highest frequency of occurrence being reported by fishers using gillnets (53.5% and 38.7%, respectively). Our interview results suggest an annual bycatch of 0.22 (95% CI = 0.13 to 0.32) for dugongs and 0.65 (95% CI = 0.40 to 0.88) for dolphins in the Malaysian Brunei Bay. Findings from this study provides important data to guide fisheries resource managers in providing protection and conservation efforts the endangered marine mammal populations.

Keywords: Local ecological knowledge (LEK), endangered marine mammals, dugong, dolphin, Brunei Bay

Introduction

Brunei Darussalam and East Malaysia (Sabah, Sarawak, and Federal Territory Labuan) share the Bay of Brunei, with about 30% of the Bay sited within Bruneian territory, and the remaining 70% within Malaysian territory. The Bay, with a width of 250, 000 hectares consists of large estuaries, coral, rainforests, seagrasses, and lagoons, making it a vital nursery ground for marine animals, such as dugongs, turtles, dolphins, and commercial fishes including shrimps in the Southeast Asian Region (Vo et al., 2013; Joseph et al., 2018; Mahmud et al., 2018). The Bay used to be rich in food resources for various kinds of marine mammals since it had a large number of fish resources (Joseph et al., 2016).

Ponnampalam (2012) stated that out of the 31 species of marine mammals in Southeast Asia, at least 27 cetaceans and one sirenian species were recorded in East Malaysian territory, which may be resident and pass through the Malaysian site of Brunei Bay. The most common species that have been sighted in coastal waters are the *Orcaella brevirostris* (Irrawaddy Dolphin) and *Sousa chinensis* (Indo-Pacific Humpback Dolphin) (Jaaman et al., 2001; Mahmud, 2016; Raman, 2017; Muda, 2018). As for the deeper waters of the Bay, the most abundant cetaceans found are the *Tursiops aduncus* (Indo-Pacific Bottlenose Dolphin), *Stenella longirostris* (Long Snout Spinner Dolphin), and *Stenella attenuata* (Pantropical Spotted Dolphin) (Jaaman et al., 2001; Raman, 2017; Muda, 2018). Besides, there have been numerous sightings of dugongs by fishers in Kudat, Sandakan, and Semporna, and viable populations are thought to exist in the Malaysian waters of Brunei Bay, which are between Labuan and Lawas (Jaaman et al., 1999; Briscoe et al., 2014).

However, the survival of marine mammals in the area is jeopardised due to human activities. Jaaman et al. (2008) reported that fishermen around Borneo Island use marine mammals for various purposes. In specific locations, dolphins and dugongs are killed, inadvertently in fisheries targeting other species and purposefully for human food or use in cultural and traditional ceremonies (Jaaman et al., 2008; Rajamani, 2013; Raman, 2017). Some fishermen said they consumed the animals for family meals, while others indicated that they traded or used the flesh as shark bait, and some others reported that they simply release/ discard the animals. It is because there seems to be a general belief that disturbing or harming the dolphin will bring bad luck. Some of the fishermen claimed that the dugong is mainly used for its flesh and medicinal purposes, such as asthma and back pain treatment by using the combination made from boiling tusk shavings, dugong blubber is consumed to strengthen and calm the body, and dugong tears are sometimes collected and used to make love charms and fragrances.

Unfortunately, information on the population status, risks, and mortality of marine mammals trapped in artisanal fishing remains poor, particularly in Borneo, since they are not routinely observed or recorded. This is because fisheries comprise numerous target species, and almost everything taken has value, either for commercial sale or personal consumption (Jaaman, 2006). In these circumstances, researchers have progressively leaned on local fishermen's knowledge to understand better artisanal fisheries and their interaction with coastal ecosystems (Hind, 2015; Leithäuser & Holzhacker, 2020; Bernos et al., 2021). Although there will always be differences in the patterns, degrees, and reliability of local knowledge among study systems, informants who spend a lot of time in landscapes containing the studied species may have knowledge that is useful for ecological and conservation management (Moore et al., 2010; Burton & Riley, 2018; Ghanbari & Turvey, 2022). Besides, making formal boat-based survey is expensive and time-consuming and need well-trained researchers with expertise because many marine mammal species are scattered across large geographic areas (Maunder & Punt, 2004). In such cases, knowledge gathered from untrained locals who share the same environments as marine aquatic animals may provide an alternative, potentially helpful source of data on species status and threats, particularly in areas where formal scientific research has been limited, but large human populations exist (Pilcher et al., 2017).

Thus, a large-scale local ecological knowledge (LEK) study of local marine fishers across Borneo was done using a questionnaire-based interview technique to address the present dearth of data on marine mammal interaction with fisheries in the Malaysian Bay of Brunei. The goal of this project was to estimate a minimum bycatch rate of dugong and dolphin, which can provide a new baseline of regional fishing methods, activities and spatial patterns of fisheries interactions with marine mammals to increase the evidence base for marine mammal conservation and management in the Brunei Bay, particularly throughout Malaysian waters.

Materials and Methods

Survey area

The study was conducted on the Malaysian side around Brunei Bay (Figure 1), located on the northwest coast of Borneo Island (4^{0}'45'to 5^{0}'02'N, 114^{0}58'-115^{0}10''to115^{0}10'E). The Bay comes under two countries, which is Malaysia (Sabah, Sarawak, and Labuan Federal Territory) and Brunei Darussalam; only 30% of the bay is located in the Brunei region, while the rest is within Malaysia's territorial waters (Mahmud, 2016). The area of interest has been known as one of the critical habitats for marine mammals in Borneo because of their biodiversity richness (Jaaman et al., 2013), which comprises seagrass beds, coral reefs, estuarine systems, extensive mangrove forest with associated mud-flats and sand-flats (Jaaman et al., 2010; Ahmad-Kamil et al., 2013). Based on their provinces and orientation toward the bay, the study area was stratified into five main districts: Lawas, Sipitang, Weston, Menumbuk, and Labuan.

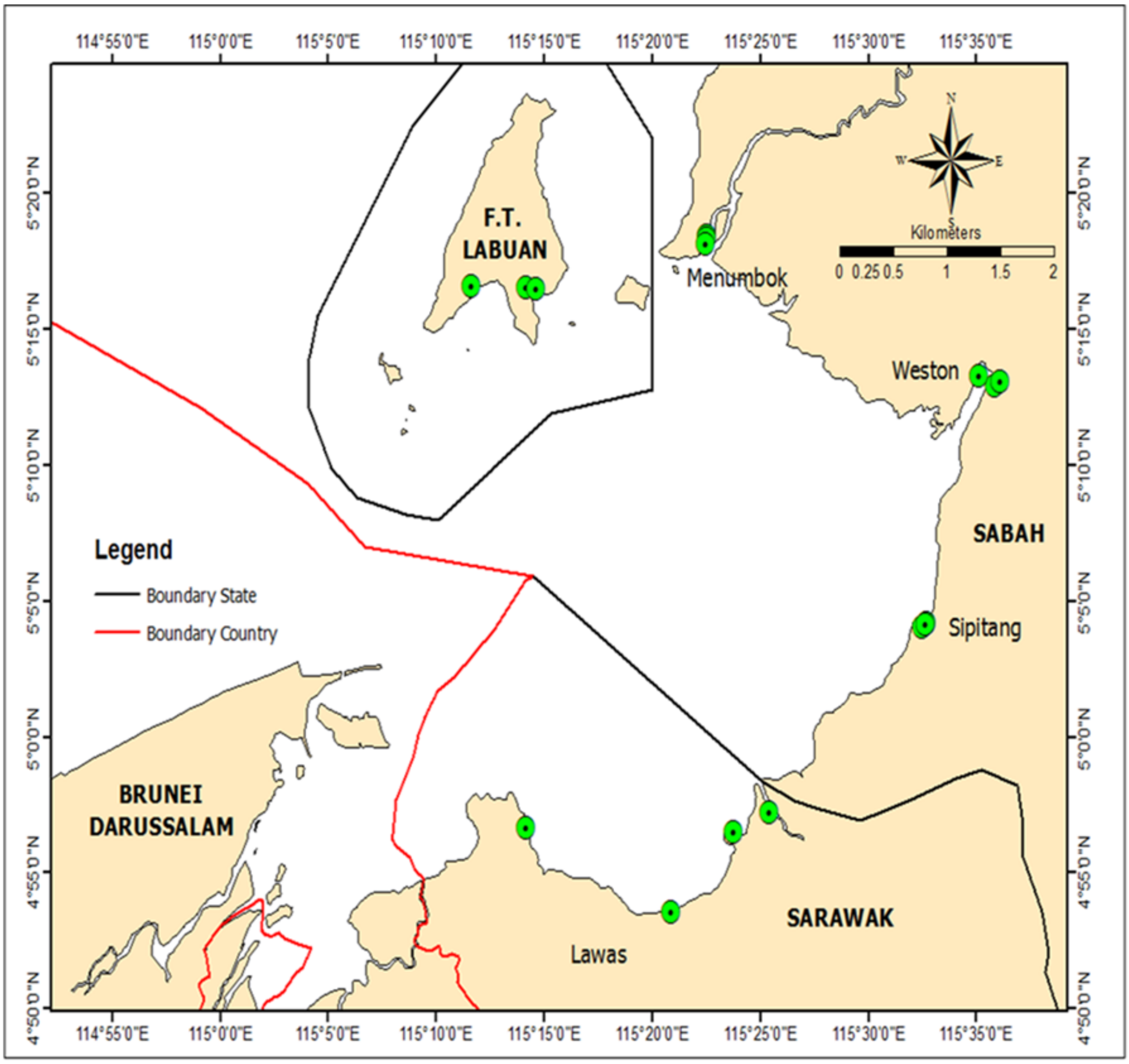

Figure 1. Map showing Brunei Bay, surrounded by Malaysia (Sarawak, Sabah and Labuan Federal Territory), and Brunei Darussalam. The green dotted-circles indicate the sites of fishing communities. Adapted from Raman (2017)

Fishers' LEK Survey

This study collected data on the fishers' LEK through a semi-structured sstandardised questionnaire-based interview survey. Conducted in the natural environment, such as fisher villages, landing jetties, and fish markets, piloted in November 2018.

The questionnaire was selected and translated from CMS-UNEP Standardized Dugong Catch/Bycatch with minor adjustments to suit local arrangements and achieve the aim of the study. The interview survey followed standard field interview procedures and suggestions from the CMS-UNEP project manual (CMS-UNEP, 2010). Paper copies of the Brunei Bay map, marine mammal guidebook (Jefferson et al., 1992; Jefferson et al., 2013), the graphic poster of marine mammals (published by UMT) and a fishing gear poster (from the FAO website) were used to aid the fishermen to confirm their answer. Besides, validation questions were also asked to assess the reliability of the answer given.

Following the acapproach outlined by Jaaman et al. (2009), before conducting the interviews, local authorities such as the officers from the Department of Fisheries and village leaders were informed and consulted to ensure adherenceto cultural guidelines. Initial contacts with fishermen were established by visiting their villages, meeting with them and their families, and seeking their consent to participate in the survey. The fishermen were then selected for interviews using a random sampling technique. These initial contacts are essential to achieve full cooperation (Hines et al., 2005; 2008), which leads to more reliable participant responses. The proper introductory statement was also given to explain the purpose of this study, and was guaranteed that all data would be anonymous. The interview will only be conducted if the fishermen consent to participate in this survey. Straightforward and general questions were first asked, followed by more profound and challenging questions towards the end of the interview to soptimise the conversations (CMS-UNEP, 2010). An open dialogue was also held to better understand the level of ecological knowledge the respondent possessed. The interview survey took about 25±5 minutes, with 3 to 5 days at each stratum to complete, which depends on the respondent's feedback.

Analysis of bycatch rates

The questionnaire used in the study consisted of 47 questions covering various aspects of local fisheries, including fishing gear commonly used, awareness of, and responses toward marine mammal bycatch. Questions about bycatch consisted of whether, how many, when, and where informants have experienced marine mammal incidental catch events, which marine mammal species and gear type were involved in these events and the informant's response to any bycatch events they had experienced. All databases were then compiled in Microsoft Excel and analysed using Statistical Package for Social Science (SPSS).

The interview data were used to calculate a 'minimum' rate of marine mammal (dugong and dolphin) bycatch in the Malaysian Brunei Bay. Data were then separated into the fishing region and gear type, employing hook and lines, seine, trawl, gillnets, and stakes. The boats sampled are assumed to be represented within each stratum; i.e. the proportion of boats reporting bycatch and calculated bycatch rates may be extrapolated to the total fleets.

The fishermen were asked whether they were involved in any bycatch events during those fishing years. If the answer was positive, they were asked how many animals they had caught the year before. Those who reported no bycatch were then asked how many animals they had caught in the previous 5 or 10 years. The minimum value was taken from the responses ranging from 1 to 2, 2 to 5, and 5 to 10, and the number of animals taken was used to estimate annual bycatch rates.

Generally, the annual bycatch of marine mammals was calculated by dividing the number of animals caught by the estimated year of incidents (following Jaaman et al., 2009). Thus, the total annual bycatch of marine mammals was a cumulative value of the yearly bycatch according to the respective variable (i.e. region, gear-type). For example, if three dugongs were caught, two in five years and the other was caught in the last two years. The calculation should be as Equation 1:

$$Total\ number\ of\ animals\ caught\ per\ year = \sum \frac{number\ of\ animal\ caught}{years} \qquad \textbf{(Equation 1)}$$

Meanwhile, the overall mean annual bycatch per boat (Equation 2) is given by the total number of animals caught per year divided by the number of interviews:

$$Mean\ annual\ by-catch\ per\ boat = \frac{total\ number\ of\ animals\ caught\ per\ year}{total\ number\ of\ interviews} \qquad \textbf{(Equation 2)}$$

Separate totals were estimated for dugongs and dolphins, as the number of respondents for both marine mammals differed. Bycatch rate estimates for the fleet total were then calculated using the number of boats in each region and gear type, published in the fisheries statistics of Malaysia in 2018 (DOFM, 2018) as a rising factor.

The mean bycatch per trip was derived from the estimated number of fishing trips every month. Most respondents said they fish daily (excluding the weather factor). Fishermen using trawls and seine nets might make up 20 trips per month since they stayed at sea for up to three days at a time. Therefore, boats using hook and lines, gillnets, and fish stakes are anticipated to make an average of 26 trips per month (following Jaaman, Lah-Anyi & Pierce, 2008).

To stimulate the data, confidence limits of the number of bycatches were determined using a bootstrap approach, which involved repeatedly re-sampling with replacement from N sets of interviews to create additional N sets. This study, 10,000 repetitions were employed, each producing an estimate of by-caught animals in each stratum, then raised to the whole fleet level. Interviews were stratified by region and gear type, and confidence limits for each region and gear type were calculated individually. By running a version of the algorithm in which all strata were sampled, the total bycatch was saved, and the confidence limits for the total across all regions and gear types were determined by bootstrap analysis, which was also repeatedly 10,000 times.

Analysis of factors that affect the reported incidence of marine mammals bycatch was based on Generalised Linear Models (GLM), fitted using SPSS software. The response variables were the presence (1) or absence (0) of bycatch of (a) dugong and (b) dolphin. The explanatory variables considered were region and gear type, all nominal variables. The models were run using a logit-link function, assuming a binomial distribution for the response variable.

The initial models had the formula (Equation 3):

$$(Y1) \sim \alpha + as.factor(region) + as.factor(gear - type) + \varepsilon_i \qquad \textbf{(Equation 3)}$$

Where Y1 is the occurrence of bycatch, α is the intercept, ε_i is the residual (unexplained information or noise, $\varepsilon_i \sim N(0, \sigma^2)$). In each case, the best-fitted model was identified using stepwise removal of non-significant terms until no further decrease in the Akaike Information Criterion (AIC) value was seen. The individual probability (p-value) associated with each explanatory variable in the final model was used to identify significant effects on the occurrence of bycatch.

Similar analyses were conducted on the variation in the number of marine mammals reported caught. As the incidence of bycatch was rare, they were then modelled with a Poisson distribution. However, the number of caught animals per year varied widely, ranging from 0.1 to 1 (i.e. the distribution was "over-dispersed). In this case, a quasi-Poisson distribution that includes a dispersion parameter and a logit link function was assumed for the response variables.

Results

Interviewee profile

A total of 364 interviews were conducted along Brunei Bay, covering Malaysian sites: Sabah, Sarawak and Federal Territory Labuan. The fishers were between 17 and 82 years old, with an average of 29.17 (SD=15.83) years of working experience in fisheries, with a strength of association between the correlation coefficient ($r=0.83$, $p<0.05$) between age and years of working experience. Besides, they were exclusively male (89.8%), and most of them from the fishers' family backgrounds (93.1%). Most of the interviewees (95.6%) reported fisheries as their primary activity, with more than half (64.0%) reporting that they depend on the daily haul as their source of income.

Most fishers (89.6%) owned the vessel in which they operated outboard motors with an average of 8.42m (SD=13.12) length of the vessel and 61.03 (SD=129.43) horsepower. Gillnets were the most frequently used fishing gear (46.2%), followed by seine nets (28.8%), stakes (8.8%), hook and lines (8.2%), and trawls (8.0%). The chi-square test showed a significant difference between the fishing gear used along the Malaysian Brunei Bay ($\chi^2=213.115$, df=4, N=364, $p<0.05$). All of the interviewed fishermen stated that they have seen at least one marine mammal in their lifetime, and most of them (n = 206/251, 82.1%) showed knowledge in the difference between the marine mammal species. From the interview data in the study area, 356 boats were sampled that provided data on dugongs, while only 146 boats provided data on dolphins.

Dugong bycatch rate estimate

Out of 356 boats sampled around The Bay of Brunei, Malaysia, fishermen from 90 (25.3%) boats indicated experiencing dugong bycatch (Table 4.9); 34.4% (N=31/90) of them were reported from the respondent around Lawas, 15.5% (N=14/90) from Sipitang, 34.4% (N=31/90) from Weston, 14.4% (N=13/90) from Menumbuk, and 1.1% (N=1/90) from Labuan. As for fishing gear used, as much as 8.9% (N=8/90) bycatches came from hook and line users, 21.1% (N=19/90) from seiners, 3.3% (N=3/90) from trawlers, 53.3% (N=48/90) from gillnetters, and 13.3% (N=12/90) from stakes.

This present study recorded at least 0.02 individuals of dugong trapped in gear annually (with an average of 0.0001 catch per boat), as stated in Table 1. By raising the interview data to fleet total, an estimated 0.22 dugongs (95% CI=0.13-0.32) were incidentally caught per year, an equivalent of two individuals of dugongs caught per 10 years by the Malaysian fishing fleets in Brunei Bay (Table 2). This value shows that it is acceptable for dugong bycatch estimated in Malaysian Brunei Bay since the landing is below the “adequate level” of no more than 2% from a total of 53 individuals of dugongs in Sabah as recommended by the Second Meeting of Parties to the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas [ASCOBANS]) (Rajamani & Marsh, 2010).

Table 1. Summary of interview-based estimates of dugong bycatch

		INTERVIEWS			ESTIMATED FISHING TRIPS		
Survey area	**Fishing gear**	**Total number of boats**	**Number of interviews**	**Number of boats with bycatch**	**Monthly per boat**	**Monthly total**	**Annual total**
Lawas	**Hook and lines**	5	8	3	26	130	1560
	Seines	3	36	6	20	60	720
	Trawl	24	0	0	20	480	5760
	Gillnets	380	70	17	26	9880	118560
	Stakes	33	16	5	26	858	10296
	All gears	445	130	31		11408	136896
Sipitang	**Hook and lines**	403	5	1	26	10478	125736
	Seines	19	19	7	20	380	4560
	Trawl	5	13	1	20	100	1200
	Gillnets	494	23	5	26	12844	154128
	Stakes	27	1	0	26	702	8424
	All gears	948	61	14		24504	294048

Table 1. Continued

		INTERVIEWS			ESTIMATED FISHING TRIPS		
Survey area	**Fishing gear**	**Total number of boats**	**Number of interviews**	**Number of boats with bycatch**	**Monthly per boat**	**Monthly total**	**Annual total**
Weston	**Hook and lines**	62	3	2	26	1612	19344
	Seines	0	6	4	20	0	0
	Trawl	0	3	3	20	0	0
	Gillnets	685	36	16	26	17810	213720
	Stakes	252	7	7	26	6552	78624
	All gears	999	55	31		25974	311688
Menumbuk	**Hook and lines**	250	1	1	26	6500	78000
	Seines	15	13	2	20	300	3600
	Trawl	35	5	0	20	700	8400
	Gillnets	675	48	10	26	17550	210600
	Stakes	20	12	0	26	520	6240
	All gears	995	79	13		25570	306840
Labuan	**Hook and lines**	119	2	1	26	3094	37128
	Seines	7	6	0	20	140	1680
	Trawl	0	12	0	20	0	0
	Gillnets	123	8	0	26	3198	38376
	Stakes	52	3	0	26	1352	16224
	All gears	301	31	1		7784	93408
All sites	**Hook and lines**	839	19	8	26	21814	261768
	Seines	44	80	19	20	880	10560
	Trawl	64	33	3	20	1280	15360
	Gillnets	2357	185	48	26	61282	735384
	Stakes	384	39	12	26	9984	119808
	All gears	3688	356	90		95240	1142880

Table 1. Continued

		DUGONG BYCATCH				
Survey area	**Fishing gear**	**Number of boats with bycatch**	**Number of animals caught annually**	**Mean annual bycatch per boat**	**Mean annual bycatch per fleet total**	**Mean annual bycatch per 1000 trips**
Lawas	**Hook and lines**	3	0.0197	0.0025	0.0123	0.0079
	Seines	6	0.0385	0.0011	0.0032	0.0045
	Trawl	0	-	-	-	-
	Gillnets	17	0.0269	0.0004	0.1460	0.0012
	Stakes	5	0.0744	0.0047	0.1535	0.0149
	All gears	31	0.0355	0.0003	0.1215	0.0009
Sipitang	**Hook and lines**	1	0.0042	0.0008	0.3385	0.0027
	Seines	7	0.0138	0.0007	0.0138	0.0030
	Trawl	1	0.0051	0.0004	0.0020	0.0016
	Gillnets	5	0.0076	0.0003	0.1632	0.0011
	Stakes	0	0.0000	0.0000	0.0000	0.0000
	All gears	14	0.0086	0.0001	0.1337	0.0005
Weston	**Hook and lines**	2	0.0437	0.0146	0.9031	0.0467
	Seines	4	0.0396	0.0066	-	-
	Trawl	3	0.0194	0.0065	-	-
	Gillnets	16	0.0255	0.0007	0.4852	0.0023
	Stakes	7	0.0592	0.0085	2.1312	0.0271
	All gears	31	0.0320	0.0006	0.5812	0.0019
Menumbuk	**Hook and lines**	1	0.0333	0.0333	8.3250	0.1067
	Seines	2	0.0203	0.0016	0.0234	0.0065
	Trawl	0	-	-	-	-
	Gillnets	10	0.0113	0.0002	0.1589	0.0008
	Stakes	0	-	-	-	-
	All gears	13	0.0090	0.0001	0.1134	0.0004
Labuan	**Hook and lines**	1	0.0135	0.0068	0.8033	0.0216
	Seines	0	-	-	-	-
	Trawl	0	-	-	-	-
	Gillnets	0	-	-	-	-
	Stakes	0	-	-	-	-
	All gears	1	0.0009	0.0000	0.0087	0.0001
All sites	**Hook and lines**	8	0.0195	0.0010	0.8611	0.0033
	Seines	19	0.0252	0.0003	0.0139	0.0013
	Trawl	3	0.0038	0.0001	0.0074	0.0005
	Gillnets	48	0.0190	0.0001	0.2421	0.0003
	Stakes	12	0.0411	0.0011	0.4047	0.0034
	All gears	90	0.0215	0.0001	0.2227	0.0002

Table 2. Estimated annual number of dugong bycatch, with bootstrap estimates of 95% confidence intervals

		INTERVIEWS		
Fishing region	**Fishing gear**	**Estimated annual bycatch for fleet total**	**95% CI (Lower Limit)**	**95% CI (Upper Limit)**
Lawas	**Hook and lines**	0.0123	0.0000	0.0264
	Seines	0.0032	0.0003	0.0087
	Trawl	-	-	-
	Gillnets	0.1460	0.0417	0.3271
	Stakes	0.1535	0.0069	0.4500
	All gears	0.1215	0.0321	0.2027
Sipitang	**Hook and lines**	0.3385	0.0000	0.1194
	Seines	0.0138	0.0044	0.0263
	Trawl	0.0020	0.0000	0.0064
	Gillnets	0.1632	0.0377	0.3196
	Stakes	-	-	-
	All gears	0.1337	0.0272	0.1806
Weston	**Hook and lines**	0.9031	0.0000	1.7222
	Seines	-	-	-
	Trawl	-	-	-
	Gillnets	0.4852	0.2873	0.7127
	Stakes	2.1312	1.4777	2.8500
	All gears	0.5812	0.4175	0.8818
Menumbuk	**Hook and lines**	8.3250	-	-
	Seines	0.0234	0.0000	0.3320
	Trawl	-	-	-
	Gillnets	0.1589	0.0594	0.2794
	Stakes	-	-	-
	All gears	0.1134	0.0486	0.4585
Labuan	**Hook and lines**	0.8033	0.0000	0.6081
	Seines	-	-	-
	Trawl	-	-	-
	Gillnets	-	-	-
	Stakes	-	-	-
	All gears	0.0087	0.0000	0.1723
All sites	**Hook and lines**	0.8611	0.3443	0.1428
	Seines	0.0139	0.0043	0.0298
	Trawl	0.0074	0.0000	0.0174
	Gillnets	0.2421	0.1345	0.4174
	Stakes	0.4047	0.0912	1.0058
	All gears	0.2227	0.1341	0.3292

A logistic model (Binomial Generalized Linear Model with logit-link function) was then fitted and estimated using multivariate linear to predict dugong bycatch occurrences with the area of occurrences and fishing gear used. The model's intercept was significant, corresponding to Labuan and gillnets at -3.32, $p < 0.05$. Instead, the model was confirmed to have significant individual effects only on the area but not the fishing gear used. From Table 3, we can see that Weston and Sipitang showed substantial effects on bycatch occurrence at $p < 0.05$. The result shows that the odds of bycatch occurrence " ("YES"" category) is 3.52 times greater for Weston than in other areas, despite the fishing gear used.

Table 3. Results from binomial logit-link GLM for variation in dugong bycatch events between different areas and boats in the Malaysian Brunei Bay

Response variable	Explanatory variable	Coefficient (Std Error)	Z-value	P-value
Dugong bycatch	**Area = Lawas**	2.0152 (1.0508)	1.918	0.0551
	Area = Menumbuk	1.6382 (1.0748)	1.524	0.1275
	Area = Sipitang	2.1239 (1.0701)	1.985	0.0472
	Area = Weston	3.5191 (1.0661)	3.301	0.0010
	Gear = Hook and lines	0.8808 (0.5450)	1.646	0.0997
	Gear = Seines	0.0992 (0.3334)	0.298	0.7660
	Gear = Trawls	-0.8811 (0.6814)	-1.293	0.1956
	Gear = Others	0.3685 (0.4154)	0.887	0.3751

*Table lists all explanatory variables in the final models. Significant terms are indicated in bold.

The quasi-Poisson GLM for variation in numbers of dugong bycatch included effects of bycatch area and gear-used type. Again, only the area of occurrence significantly impacted the number of dugongs reported caught. As we can see from Table 4, Lawas and Weston show statistically significant effects at $p<0.05$. it has been said that the expected log count for dugong caught in Lawas increases by 2.13 and 3.11 in Weston compared to Labuan. Again, no significant effects on the number of dugongs reported caught in the fishing gear used.

Table 4. Results from quasi-Poisson GLM for variation in numbers of dugong reported caught incidentally between different areas and boats in Malaysian Brunei Bay

Response variable	Explanatory variable	Coefficient (Std Error)	t-value	P-val
Dugong bycatch	**Area = Lawas**	2.1291 (1.0859)	1.961	0.05
	Area = Menumbuk	1.5795 (1.1100)	1.423	0.16
	Area = Sipitang	2.0988 (1.0976)	1.912	0.06
	Area = Weston	3.1110 (1.0845)	2.877	0.00
	Gear = Hook and lines	0.4323 (0.3650)	1.186	0.24
	Gear = Seines	0.2101 (0.2450)	0.858	0.39
	Gear = Trawls	**-0.6230 (0.5651)**	**-1.102**	**0.27**
	Gear = Others	**0.0852 (0.3150)**	**0.270**	**0.79**

*Table lists all explanatory variables in the final models. Significant terms are indicated in bold

Dolphin bycatch

A total of 146 boats were sampled, of which 62 (42.5%) boats indicated the occurrence of incidental catch of dolphins (Table 5). In contrast to dugong, the highest dolphin bycatch events were reported around Lawas (N=25/62, 40.3%), followed by Menumbuk (N=11/62, 17.7%), Weston (N=10/62, 16.1%), Sipitang (N=7/62, 11.3%) and Labuan (N=9/62, 14.5%), reported caught in all fishing gear types, but the highest was shown by the gillnets (N=24/62, 38.7%).

About 0.03 individuals of dolphins were reported caught incidentally in fishing gear per year, with an average catch of 0.0002 per boat. Table 5 sthat Lawas had the highest number of boats reporting dolphins bycatch, the number of dolphins reported caught, mean annual bycatch per boat, estimated annual bycatch per fleet total, and estimated mean bycatch per 1000 fishing trips.

By raising the interview data to fleet total, an estimated 0.65 (95% CI=0.40-0.88) dolphins were caught incidentally per year, or seven individuals of dolphins were caught per 10 years in the Malaysian Brunei Bay. Assuming dolphin species caught in Borneo are Irrawaddy dolphin, Indo-pacific humpback dolphin, and Indo-pacific finless porpoise and that species population in Borneo is estimated to be 153 individuals (Minton *et al*., 2016), 2% of the population for maximum acceptable annual bycatch is approximately three individuals (or 0.003 bycatches per 1000 trips). Therefore, the figure from bootstrap estimates (Table 6) proved to have an acceptable enough value for the total dolphin bycatch in Malaysian Brunei Bay.

Table 5. Summary of interview-based estimates of dolphins bycatch

		INTERVIEWS			ESTIMATED FISHING TRIPS		
Survey area	**Fishing gear**	**Total number of boats**	**Number of interviews**	**Number of boats with Bycatch**	**Monthly per boat**	**Monthly total**	**Annual total**
Lawas	**Hook and lines**	5	3	3	26	130	1560
	Seines	3	10	10	20	60	720
	Trawl	24	0	0	20	480	5760
	Gillnets	380	12	11	26	9880	118560
	Stakes	33	1	1	20	660	7920
	All gears	445	26	25		11210	134520
Sipitang	**Hook and lines**	403	1	3	26	10478	125736
	Seines	19	11	5	20	380	4560
	Trawl	5	4	0	20	100	1200
	Gillnets	494	9	2	26	12844	154128
	Stakes	27	0	0	20	540	6480
	All gears	948	25	10		24342	292104
Weston	**Hook and lines**	62	3	3	26	1612	19344
	Seines	0	2	1	20	0	0
	Trawl	0	0	0	20	0	0
	Gillnets	685	12	5	26	17810	213720
	Stakes	252	7	4	20	5040	60480
	All gears	999	24	13		24462	293544
Menumbuk	**Hook and lines**	250	2	3	26	6500	78000
	Seines	15	6	0	20	300	3600
	Trawl	35	3	0	20	700	8400
	Gillnets	675	35	6	26	17550	210600
	Stakes	20	9	5	20	400	4800
	All gears	995	55	14		25450	305400
Labuan	**Hook and lines**	119	1	1	26	3094	37128
	Seines	7	3	3	20	140	1680
	Trawl	0	8	5	20	0	0
	Gillnets	123	1	0	26	3198	38376
	Stakes	52	3	0	20	1040	12480
	All gears	301	16	9		7472	89664

Table 5. Continued

		INTERVIEWS			ESTIMATED FISHING TRIPS		
Survey area	**Fishing gear**	**Total number of boats**	**Number of interviews**	**Number of boats with Bycatch**	**Monthly per boat**	**Monthly total**	**Annual total**
All sites	**Hook and lines**	839	10	4	26	21814	261768
	Seines	44	32	19	20	880	10560
	Trawl	64	15	5	20	1280	15360
	Gillnets	2357	69	24	26	61282	735384
	Stakes	384	20	10	20	7680	92160
	All gears	3688	146	62		92936	1115232

		DOLPHIN BYCATCHES				
Survey area	**Fishing gear**	**Number of boats with bycatch**	**Number of animals caught annually**	**Mean annual bycatch per boat**	**Mean annual bycatch per fleet total**	**Mean annual bycatch per 1000 trips**
Lawas	**Hook and lines**	3	0.0980	0.0327	0.1633	0.1047
	Seines	10	0.0622	0.0062	0.0187	0.0259
	Trawl	0	-	-	-	-
	Gillnets	11	0.0594	0.0050	1.8810	0.0159
	Stakes	1	0.1200	0.1200	3.9600	0.5000
	All gears	25	0.0673	0.0130	1.0471	0.0078
Sipitang	**Hook and lines**	3	-	-	-	-
	Seines	5	0.0241	0.0022	0.0416	0.0091
	Trawl	0	-	-	-	-
	Gillnets	2	0.0110	0.0012	0.6038	0.0039
	Stakes	0	-	-	-	-
	All gears	10	0.0144	0.0014	0.2271	0.0008

Table 5. Continued

Survey area	Fishing gear	Number of boats with bycatch	Number of animals caught annually	Mean annual bycatch per boat	Mean annual bycatch per fleet total	Mean annual bycatch per 1000 trips
		DOLPHIN BYCATCHES				
Weston	**Hook and lines**	3	-	-	-	-
	Seines	1	0.0102	0.0051	-	-
	Trawl	0	-	-	-	-
	Gillnets	5	0.0112	0.0009	0.6393	0.0030
	Stakes	4	0.0286	0.0041	1.0296	0.0170
	All gears	13	0.0148	0.0021	0.6186	0.0021
Menumbuk	**Hook and lines**	3	-	-	-	-
	Seines	0	-	-	-	-
	Trawl	0	-	-	-	-
	Gillnets	6	0.0095	0.0003	0.1832	0.0009
	Stakes	5	0.0684	0.0076	0.1520	0.0317
	All gears	14	0.0172	0.0014	0.1408	0.0005
Labuan	**Hook and lines**	1	0.0270	0.0270	3.2130	0.0865
	Seines	3	0.0474	0.0158	0.1106	0.0658
	Trawl	5	0.0256	0.0032	-	-
	Gillnets	0	-	-	-	-
	Stakes	0	-	-	-	-
	All gears	9	0.0234	0.0063	0.2217	0.0025
All sites	**Hook and lines**	4	0.0321	0.0032	2.6932	0.0103
	Seines	19	0.0328	0.0010	0.0451	0.0043
	Trawl	5	0.0137	0.0009	0.0585	0.0038
	Gillnets	24	0.0185	0.0003	0.6319	0.0009
	Stakes	10	0.0468	0.0023	0.8986	0.0098
	All gears	62	0.0259	0.0002	0.6542	0.0006

Table 6. Estimated annual number of dolphin bycatch, with bootstrap estimates of 95% confidence intervals

		INTERVIEWS		
Fishing region	**Fishing gear**	**Estimated annual bycatch for fleet total**	**95% CI (Lower Limit)**	**95% CI (Upper Limit)**
Lawas	**Hook and lines**	0.1633	0.0900	0.2000
	Seines	0.0187	0.0120	0.0260
	Trawl	-	-	-
	Gillnets	1.8810	1.2290	2.5810
	Stakes	3.9600	-	-
	All gears	1.0471	0.5610	1.5810
Sipitang	**Hook and lines**	-	-	-
	Seines	0.0416	0.0110	0.0790
	Trawl	-	-	-
	Gillnets	0.6038	0.0000	1.4840
	Stakes	-	-	-
	All gears	0.2271	0.0110	0.5730
Weston	**Hook and lines**	-	-	-
	Seines	-	-	-
	Trawl	-	-	-
	Gillnets	0.6393	0.1740	1.2040
	Stakes	1.0296	0.2570	1.8000
	All gears	0.6186	0.2790	0.9930
Menumbuk	**Hook and lines**	-	-	-
	Seines	-	-	-
	Trawl	-	-	-
	Gillnets	0.1832	0.0420	0.3760
	Stakes	0.1520	0.0410	0.2760
	All gears	0.1408	0.0480	0.2700
Labuan	**Hook and lines**	3.2130	-	-
	Seines	0.1106	0.0780	0.1370
	Trawl	-	-	-
	Gillnets	-	-	-
	Stakes	-	-	-
	All gears	0.2217	0.0060	0.7150
All sites	**Hook and lines**	2.6932	0.3239	5.4915
	Seines	0.0451	0.0290	0.0630
	Trawl	0.0585	0.0164	0.1059
	Gillnets	0.6319	0.3876	0.9114
	Stakes	0.8986	0.3937	1.4703
	All gears	0.6542	0.4022	0.8806

Using binomial GLM, only the region significantly affected the overall reported incidence of dolphin bycatches in the Malaysian Brunei Bay. The final model was statistically significant, $\chi^2(8) = 56.86, p < 0.05$. The model explained 43.0% (Nagelkerke R^2) of the variance in bycatch occurrence and correctly classified 57.5% of cases. Lawas and Menumbuk were reported to have significant effects on bycatch occurrences, and the results show that the odds of having dolphin bycatch occurrence ” (“YES"” category) for both areas are two times greater than in the other regions. There were no effects of fishing gear on bycatch events (Table 7).

The quasi-Poisson GLM for variation in dolphin numbers reported caught in the Malaysian Brunei Bay. Again, the only areas of occurrences shown to affect dolphins caught, with Lawas and Menumbuk significantly tend to have double the number of dolphins caught compared to the other areas since both have higher occurrences of bycatch. Fishing gear used seems to have no significant effect on the number of dolphins caught (Table 8).

Table 7. Results from binomial logit-link GLM for variation in dolphin bycatch events between different areas and boats in Malaysian Brunei Bay

Response variable	Explanatory variable	Coefficient (Std Error)	Z-value	P-value
Dolphin bycatch	**Area = Lawas**	2.9939 (1.2393)	2.416	0.0157
	Area = Menumbuk	-1.7309 (0.7466)	-2.318	0.0204
	Area = Sipitang	-1.3810 (0.7796)	-1.771	0.0766
	Area = Weston	-0.6892 (0.8043)	-0.857	0.3915
	Gear = hook and lines	-0.7433 (0.9872)	-0.753	0.4515
	Gear = Seines	0.7853 (0.5921)	1.326	0.1847
	Gear = Trawls	-0.1878 (0.8147)	-0.231	0.8177
	Gear = Others	0.8647 (0.5926)	1.459	0.1445

*Table lists all explanatory variables in the final models. Significant terms are indicated in bold

Table 8. Results from quasi-Poisson GLM for variation in numbers of dolphins reported caught incidentally between different areas and boats in Malaysian Brunei Bay

Response variable	Explanatory variable	Coefficient (Std Error)	t-value	P-value
Dolphin bycatch	**Area = Lawas**	1.0983 (0.3677)	2.987	**0.0033**
	Area = Menumbuk	-1.1656 (0.4236)	-2.752	**0.0067**
	Area = Sipitang	-0.4811 (0.4349)	-1.107	0.2705
	Area = Weston	-0.5038 (0.4319)	-1.167	0.2454
	Gear = hook and lines	0.0709 (0.3364)	0.211	0.8333
	Gear = Seines	0.1185 (0.2240)	0.529	0.5977
	Gear = Trawls	-0.3823 (0.4975)	-0.768	0.4436
	Gear = Others	0.4400 (0.3101)	1.419	0.1582

*Table lists all explanatory variables in the final models. Significant terms are indicated in bold

Discussion

Jaaman (2006) has mentioned that the amount of marine mammal bycatch in Southeast Asian fisheries was significantly higher than previously thought. There is no evidence that this problem has been adequately monitored anywhere in the area, especially around the Malaysian Brunei Bay. Both datasets (dugong and dolphin) used in this study found significant differences in marine mammal bycatch incidents in the survey area but no difference in the fishing gear used. Thus, this may indicate that the bycatch incidents may differ because of the number of marine mammals that occur, which may occur in all types of gear. Despite other large fleets utilising different kinds of equipment, most bycatches were found to occur in a gillnet. This is expected to be a widespread fishing gear in Malaysia and other emerging countries since the commercial usage of gillnets was sparked by the development of nylon nets in the 1960s (Marsh et al., 2011). Gillnets are not only less expensive, but they are also easier to handle, last longer, require less maintenance, and can catch a large number of fish efficiently since they are invisible in waters (Marsh et al., 2011; Briscoe et al., 2014; Raman, 2017). Thus, these efforts to document the magnitude of bycatches should, in general, focus on gillnets fisheries since gillnets have been srecognised as the leading cause of cetaceans and dugong bycatches worldwide (Reeves et al., 2013; Raman, 2017).

In the case of marine mammal bycatches, boat fishing in the Malaysian Brunei Bay, , reported a higher number of incidents involving dolphins than dugongs. The results differ from previous studies (e.g. Jaaman, 2006; Raman, 2017). This may be because of the number of marine mammal occurrences since most young fishermen stated that they rarely saw dugong, and at most never saw dugong at all, compared to dolphins. Although many fishermen claim that cetaceans are far more competent than dugongs in avoiding fishing nets, they can sometimes become caught when the animals aggressively pursue their meal (Reeves et al., 2013). Jaaman et al. (2009) stated that dugongs were more vulnerable to fishing gear than cetaceans. Several factors may have influenced this. First, gillnets are commonly used to catch fish in shallow locations with strong tidal fluctuations, such as seagrass meadows. Raman (2017) mentioned that an area with a seagrass bed is the preferable location for dugongs, so it is possible that the dugongs were likely to be captured or trapped, especially at night. Cetaceans caught in nets generally battled vigorously and were likelier to release themselves, but dugong was frequently discovered dead.

Taking into account the marine mammal population around Borneo is as follows: the dugong population was estimated to be around 53 individuals (Rajamani and Marsh, 2010), while the cetacean population was about 153 (Minton et al., 2016). Assuming that marine mammal bycatches reported in the bay come from the same populations and the 2% of anthropogenic removal (ASCOBANS, 1997) is exclusively from bycatches in fisheries, there will be an upper limit of one dugong and three cetaceans or a total of four marine mammals caught annually. The estimated annual number of 0.22 dugongs (95% CI=0.13-0.32) and 0.65 dolphins (95%=0.40-0.88) were found to lie below the maximum value of annual bycatch. Therefore, this study's figure from bootstrap estimates proved to have an acceptable enough value for marine mammal bycatch in Malaysian waters of Brunei Bay.

As we all know that the estimate of the bycatching rate and the number of animals taken annually is based on an interview survey, which is obviously subject to a range of errors and biases. Furthermore, the Summary of Annual Fisheries Statistics Sabah 2019 (DOFS, 2019) used in the estimates is not up to date because the number of fishermen, boats, and fishing gear published in the summary is based on a listing made in 2018. The number of full-time fishermen is probably an underestimation; the number of illegal immigrants active in the industry has not been ascertained but could run into thousands. Many unlicensed boats and gear of the traditional types and part-time fishermen were observed during the survey but were not listed (no estimate) in the summary. But at most, the data can be thought of as providing a rough indication of the scope of the problem. Furthermore, all the mentioned issues need to be addressed since updated information on the life history parameters, on-site catching monitoring data, and an accurate estimate of the absolute abundance of cetaceans and dugongs in the regions are essential to determine the reliability and sustainability of the bycatch catch estimates.

A previous study suggested that the placement of observers on board fishing boats is the most reliable method for collecting information regarding marine mammal bycatch (Moore et al., 2010; Moore et al., 2021; Wade et al., 2021), but such a monitoring program is lacking in Malaysia. Besides, fishermen frequently refused to voluntarily accept observers' boarding, especially in boats employing fishing gear that are known to catch cetaceans. Even within the European Union, many governments of the Member States have not established routine monitoring of marine mammal catches and kills in fisheries (Morizur et al., 1999; Lopez et al., 2003) despite an obligation to do this under Article 12.4 of the Habitats Directive (92/43/EEC).

Here are the suggestions to address the issue of fisheries bycatch that might be suitable for adoption in the remote Malaysian side of the Brunei Bay. The first recommendation is community participation. Engaging fisheries communities in bycatch mitigation programs can be highly relevant because the involvement is voluntary, especially in small-scale fisheries such as the Brunei Bay. Previous studies have demonstrated that engaging people from fisheries communities can strengthen the implementation of long-term solutions to human conflicts with marine mammals (Farr et al., 2018; Berkstrom et al., 2019). The authorities must embrace the connection to reclaim full involvement and commitment from local communities. As such, responsible parties should assist the people in need, care for their welfare, and ensure their opinions are heard. The general conflicts of human-marine mammals, especially marine mammal bycatch, can be overcome by creating capacity through this win-win situation.

It is advised that management, enforcement agencies, and community leaders work promptly to develop a joint and committed monitoring program to uncover substantial direct or indirect captures of marine mammals in the Brunei Bay. This approach should reduce dangers via education, backed up by stiff consequences for violating regulations. However, this must be done with caution since legislation enforcement preventing direct captures or landing of incidental catches of marine mammals has made gathering information on such takes more difficult in several nations (Mintzer, 2018; Bering et al., 2022). Furthermore, educating the fisheries communities about fishing rules and environmental conservation is critical since enforcing the law across a vast region may be difficult and expensive. If such communities must reduce or discontinue fishing, other livelihoods such as mariculture or ecotourism should be supported. Furthermore, these communities should also have a significant role in managing, conserving, and utilising natural resources. These kinds of alternative enforcement would encourage the communities' involvement in species monitoring.

On the other hand, marine mammal-fisheries issues in the Brunei Bay can be effectively solved by an integrated framework between the state and its neighbouring nations. Malaysian state integration can significantly bring together some necessary components in fisheries interaction with marine mammal evaluation and alleviation. A robust platform should be given for people to discuss the crucial issues that may be addressed to a higher constitution, such as the Brunei Darussalam territory. This can be seen from the achievement of the UMT Marine Mammals team, founded by the First Institute of Oceanography, China, which managed to reach an agreement with the Brunei Government to undertake marine mammal research in Bruneian territory in the Brunei Bay (e.g. Haji-Ismail et al., 2021; Azizul et al., 2022). This can later be followed by identifying the specific mechanism of achieving a cross-sectoral integration of legislation. However, this study proposes that the integration should not only be limited to the Brunei Bay itself, but it should be expanded to the other parts of Borneo, such as the Balikpapan Bay (East Kalimantan), the Derawan Island (North Kalimantan), the Kumai/Kotawaringin (Central Kalimantan), or Karimata Bay (West Kalimantan) by conducting an international collaboration with the 'Indonesian's research team, as well as the other parts of Malaysia.

Conclusion

Rapid assessment of the interview survey allowed us to collect considerable information about the scharacterisation of artisanal fisheries and their interaction regarding bycatch mortality over a large geographic area at a relatively low cost. We believe this approach has the potential to become an important conservation tool for studying bycatch and their interaction with artisanal fisheries. However, methodological improvement to the interview survey protocol should be implemented to increase the reliability of the data.

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Length-Weight Relationships and Condition Factors of Kawakawa *Euthynnus affinis* and Longtail Tuna *Thunnus tonggol* from Sarawak, Malaysia

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Abstract

Length-weight relationships (LWR) and condition factors (K) were determined for two neritic tuna species *Euthynnus affinis* and *Thunnus tonggol*, caught in Sarawak waters. Specimens were collected from five locations around Sarawak between 2016-2019. The r2 value of the LWR for each species re both close to 1 (>0.9), indicating a highly significant relationship attributed to the length and weight of the fish species . The K values are 1.94 and 1.97, and the values of b in the LW equation are 2.53 and 2.59 for *E. affinis* and *T. tonggol*, respectively. The b<3 values indicates negative allometric growth patterns, where the growth rate of body length is faster than the weight gain. These values fall within the published range of 2.50 to 3.50 for neritic tuna species in the region. The results of this study provide the basic life history parameters and the general condition of the two species, *E. affinis* and *T. tonggol*, useful for our tuna fish stock assessment efforts in Sarawak waters.

Keywords: Tuna fisheries, *Euthynnus affinis*, *Thunnus tonggol*, FiSAT, allometric growth, Sarawak

Introduction

The fisheries industry plays an essential role in the economy of countries globally, including Malaysia. Landings of marine fish increased from 1,482,900 tonnes (2013) to 1,455,446 tonnes in 2019 (DOFM, 2021). Landings slightly decreased in 2020 at 1,383,299 tonnes due to a lack of vessel operations, resulting from the restrictions on the re-entry of foreign labour (DOSM, 2021).

To date, Malaysia's per capita consumption is 46.9 kg per year, which is the second highest in the Southeast Asia region, behind only Cambodia (63.2 kg per year), but higher than the global average of 20.5 kg per year (Malay Mail, 2020). Therefore, the management and conservation of marine resources should be prioritised to ensure the fishing sector's sustainability and contribute to developing the target group's living standards, food safety, and the national economy. However, according to the Department of Fisheries Malaysia (DOFM) as reported by Goh et al. (2021), despite an increase in the fishing effort, where issued fishing licenses increased by 15% from 2009 to 2014, the number of fish landings remained constant. This suggests a depletion in the fish stock in the ocean. This was agreed to by Gambang et al. (2003), where marine fish production from captured fisheries has reached the maximum sustainable yield (MSY) in the West Coast and East Coast Exclusive Economic Zones (EEZ) in Peninsular Malaysia. According to Gambang et al. (2003), the East Malaysia EEZ, particularly in Sarawak, has a bright potential to be developed as a fishery resource.

The EEZ of East Malaysia has an approximate area of 250,000 km^2, whereas the EEZ of Sarawak has an estimated 160,000 km^2 (Hadil, 2007). Sarawak reported the highest biomass for fish, at 1,273,081 tonnes, with 340,013 tonnes of small pelagic yet to be exploited (JPLS, 2018). About 4.6% of Malaysia's marine fish landings in 2018 were contributed to by neritic tuna (Sallehudin et al., 2019). Neritic tuna species in Malaysia consist of the longtail tuna (*T. tonggol*), kawakawa (*E. affinis*), and frigate tuna (*Auxis thazard* and *Auxis rochei*) (Adnan et al., 2015). They are the second most abundant landed by purse seines, with the longtail tuna dominating the landings, followed by the kawakawa and frigate tuna in Kuala Perlis, Malaysia (Sallehudin et al., 2019).

Thunnus tonggol and *E. affinis* are distributed exclusively in the Indo-Pacific waters (Rohit et al., 2012; Kasim et al., 2020). *Thunnus tonggol* grows to a maximum size of 136 cm fork length and 35.9 kg (Collette & Nauen, 1983). It tends to form schools of different sizes, where fish, cephalopods and crustaceans are their common prey (Seafood Watch Consulting Researcher, 2015). *Euthynnus affinis* grows to a maximum fork length of 100 cm with a maximum weight of 13.6 kg (Collette & Nauen, 1983). *Euthynnus affinis* usually forms multispecies schools with small *Thunnus albacares*, *Katsuwonus pelamis*, *Auxis* spp. and *Megalaspis cordyla*, consisting of 100 to over 5,000 individuals (Sulistyaningsih et al., 2014). It is an opportunistic predator feeding on fish, shrimps and cephalopods (Collette & Nauen, 1983).

Despite their significant contributions and growing demands in recent years, the population dynamics study, such as growth, spawning season, recruitment and mortality, were still lacking in Sarawak waters. Management and conservation of marine resources should be prioritised to ensure that the fishing industry remains sustainable and contributes to developing the target group's living standards and the national economy. Therefore, the length frequency distribution, the length-weight relationship (LWR) of the two species, and the condition factors were assessed in this study. These parameters will act as a preliminary fisheries management and conservation assessment.

Materials and Methods

Sampling area

Five sampling locations, namely Sematan, Lundu, Kuching, Bintulu and Miri, were identified to represent this study (Figure 1).

Figure 1. Sampling locations for *E. affinis* and *T. tonggol* from Sarawak, Malaysia

Fish sampling

Samplings of the fish were conducted at the specified locations, and the data was pooled between 2016 to 2019. The fish were caught by Sarawak-registered commercial fishermen using various fishing gears, such as the drift net, the purse seine and the beam trawl. A total of 2,154 *E. affinis* and 2,605 *T. tonggol* were examined across five locations.

Data Analysis

Population parameters

The *E. affinis* and *T. tonggol* population growth were estimated based on the length frequency and length-weight relationships. Upon landing at the jetty, the fork length (FL) of each fish was measured in centimetres and weighed to the nearest 0.1 g (body weight, BW) using an electronic balance (Model: Camry EK 3250). The length at the first maturity (L_m) was estimated using Equation 1 adapted from Binohlan and Froese (2009):

$$\log\ (L_m) = -0.1189 + 0.9157 * \log\ (L_{max}) \qquad \textbf{(Equation 1)}$$

Where, L_m is the length at first maturity, and L_{max} refers to the maximum length. The length-weight relationship (LWR) was analysed using the FAO-ICLARM Fish Stock Assessment Tools (FiSAT II) software to obtain a regression analysis (Quinn & Deriso, 1999). The LWR equation is stated as in Equation 2:

$$W = aL^b \qquad \textbf{(Equation 2)}$$

Where, W is the weight of the fish, L is the total fish's length, and 'a' and 'b' are constants. The values of the constants were estimated using the least square linear regression using a log-log transformed data (Equation 3):

$$\log_{10} W = \log_{10} a + b \log_{10} L \qquad \textbf{(Equation 3)}$$

The value of b, ideally 3.0, represents an isometric growth due to environmental conditions or the fish' condition (Ricker & Carter, 1958). When b is less than 3.0, the fish is slimmer with an increased length and is known as a negative allometric growth factor. When b is more than 3.0, the fish becomes heavier. Thus, it demonstrates a positive allometric growth, reflecting the optimum growth conditions. The coefficient of determination (r^2) was used to indicate the quality of the linear regression. A 95% confidence limit for the parameters and the statistical significance level of r^2 was estimated.

Fulton's condition factor

Fulton's condition factor (K) (Equation 4) was used to estimate the fish's body conditions. The condition factor was analysed according to the equation (Froese, 2006):

$$K = \left[\frac{W}{L^3}\right] \times 100 \qquad \textbf{(Equation 4)}$$

Where, K is the Fulton's condition factor, W is the weight of the fish in grams, and L is the length of the fish in centimetres. A conditional factor ≥ 1 implies a good feeding level and suitable environmental conditions, while a conditional factor < 1 refers to no proper habitat conditions for this species in the region.

The analysis was done by combining the data of each species from across the five sampling stations.

Results and Discussion

A total of 2,154 tails of *E. affinis* and 2,605 tails of *T. tonggol* were collected in this study.

Length frequency

A preliminary analysis of the size distribution of *E. affinis* (Figure 2) showed a length frequency distribution range between 17.0 – 90.0 cm with two modes. The highest size distribution was observed at 33.0 – 34.0 cm with 325 tails, followed by the size distribution range between 32.0 – 33.0 cm (305 tails). The average weight for this species was 911.0 g.

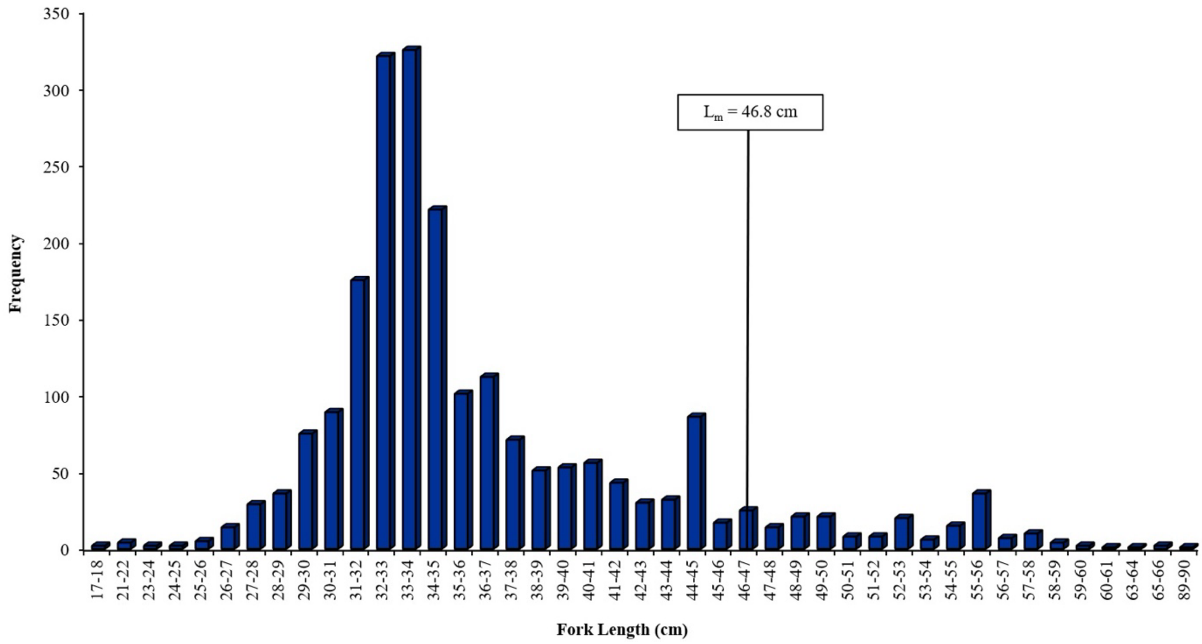

Figure 2. Length frequency graph for *E. affinis*

The size distribution of the *E. affinis* in present study was slightly larger. In northern Peninsular Malaysia, the *E. affinis* was 15.0 – 57.5 cm (Effarina et al., 2019). A similar study from Kuala Perlis indicated that the size distribution was around 13.0-59.0 cm (Adnan et al., 2015). In Tanjung Luar waters, Agustina et al. (2018) reported that the size range was between 24.0 – 71.0 cm. The significant catches in the present study were in agreement with the work by Effarina et al. (2019) and Adnan et al. (2015). Table 1 shows the size distribution of the *E. affinis* in other localities in Malaysia and Indonesia.

Table 1. Size distribution for *E. affinis* in different areas

Locality	Size distribution (cm)
Sarawak (Present Study)	17.0 – 90.0
Northern Peninsular Malaysia	15.0 – 57.5
Kuala Perlis, Peninsular Malaysia	13.0 – 59.0
Tanjung Luar Waters, West Nusa Tenggara, Indonesia	24.0 – 71.0

The length at first maturity (L_m) was 46.8 cm (Figure 2); about 92% of the *E. affinis* landings in the area were mostly juveniles. The result obtained in this study was slightly larger than the length at first maturity as reported in Kuala Perlis, 43.0 cm and in the Straits of Malacca, 41.0 cm (Sallehudin et al., 2016; Wagiyo et al., 2018). Both results showed that most of the *E. affinis* landed were caught before reaching first maturity.

As shown in Figure 3, the size range of *T. tonggol* landing was between 20.0 – 80.0 cm. The most common size caught was 41.0 – 42.0 cm, with 210 tails, followed by 39.0 – 40.0 cm, with 193 tails. The average weight of the *T. tonggol* was 1241.9 g, and the length at first maturity (L_m) was 42.1 cm.

A similar analysis for the *T. tonggol* size distribution in this study was slightly more prominent compared to other areas. In Kuala Perlis, the size ranged from 21.0 – 54.0 cm (Adnan et al., 2015). Other researchers, such as Griffiths et al. (2019) and Risti et al. (2019), recorded the catch size of the *T. tonggol* which ranged between 23.8-125 cm in Australian waters and 39.5 – 67.5 cm in Aceh Barat Daya waters. The most common size obtained in this study was in agreement with the work by Adnan et al. (2015). Table 2 presents the size distribution across different areas.

About 69% of the *T. tonggol* caught in Sarawak waters were juveniles. The length at first maturity (L_m) in this study was nearly identical to the L_m of *T. tonggol* caught in the Java Sea, 42.3 cm (Hidayat et al., 2020). *T. tonggol* was reported to attain a L_m of 41.1 cm in the South China Sea (Hidayat and Noegroho, 2018), and 51.1 cm in the Indian coast (Abdussamad et al., 2012).

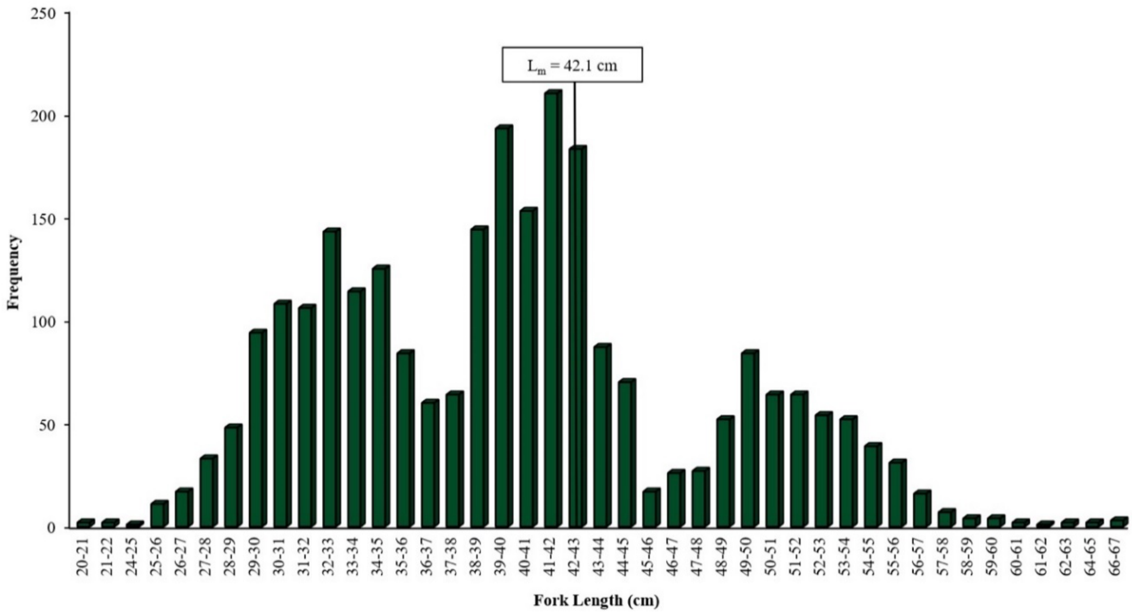

Figure 3. Length frequency graph for *T. tonggol*

Table 2. Size distribution for *T. tonggol* in different areas

Locality	Size distribution (cm)
Sarawak (Present Study)	20.0 – 80.0
Kuala Perlis	21.0 – 54.0
Australia	23.8 – 125.0
Aceh Barat Daya	39.5 – 67.5
Persian Gulf and Oman Sea	27.0 – 107.0

The results suggested that the size distribution for both species caught in Sarawak waters was bigger than in other areas. The L_m value obtained suggested that most of the caught fish were below the size of first maturity, indicating that they did not have the chance to spawn for the first time. The differences in size at maturity for the same species may be due to geographical factors, fishing pressure, stock density, and food and water temperatures (see Hidayat et al., 2020).

Length-weight relationship (LWR)

The results of the LWR analysis for both fish are depicted in Figure 4 (a and b). The intercept 'a' of the *E. affinis* (Figure 4a) was 0.0969, while the exponent b was 2.53, with a correlation coefficient of r^2 = 0.91. The LWR analysis of the *T. tonggol* (Figure 4b) recorded 0.0807 for the intercept 'a', whilst the exponent b was 2.59 with a correlation coefficient of r^2 = 0.94. A high value for the coefficient of determination (> 0.90) indicated a high degree of correlation and a better fit of the length-weight relationship.

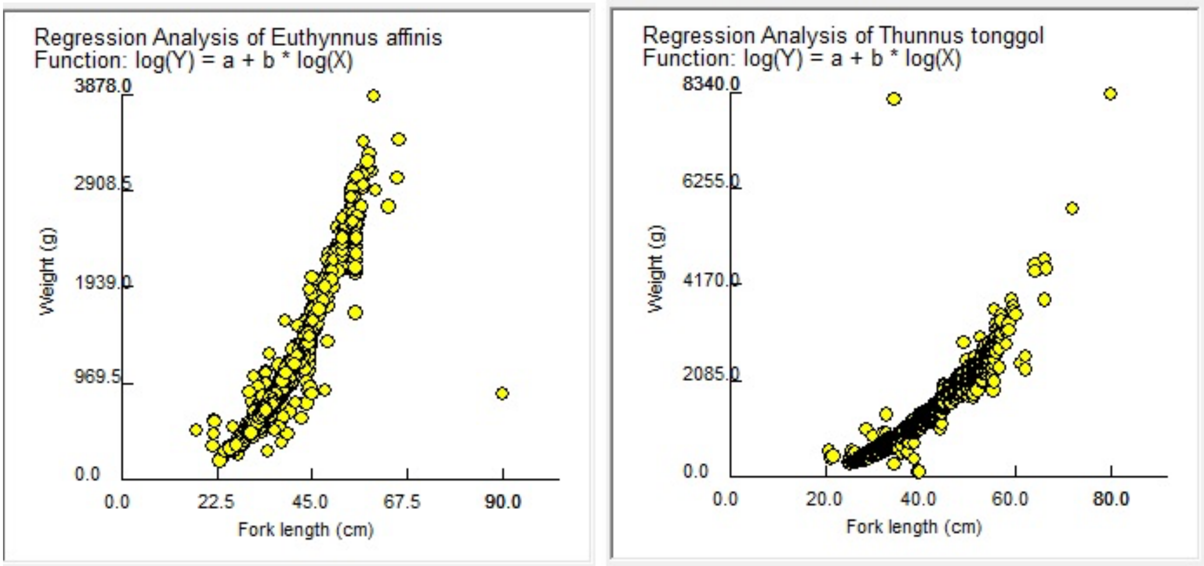

Figure 4a (left) & 4b (right). Length-weight relationship graph for (a) *E. affinis* and (b) *T. tonggol*

The constant value of 'b' depicted important information for the fish's growth. This value was crucial in assessing the well-being of the fish (Mohamad Radhi et al., 2017). The analysis showed that the exponent 'b' values referred to the negative allometric growth slightly deviating from the cube law, which stated that the ideal value was 3, i.e., an isometric growth value (Jisr et al., 2018). This showed that the increment in the weight of both fish was not proportional to its length, thus increasing the fish's length, resulting in a less rotund fish shape (Mohamad Radhi et al., 2017). However, according to Mariasingarayan et al. (2018), the acceptable range of 'b' value lies between 2.50 to 4.00, which agrees with our estimation. This was agreed to by Froese (2006), as cited in Yasemi et al. (2017), which also reported that the acceptable range of the 'b' value was between 2.50 and 3.50. The value of 'b' obtained in this analysis was small compared to different locations worldwide (Table 3). The negative allometric growth pattern for both species may be due to several parameters, for example, temperature, food supply, spawning conditions, dissolved oxygen contents in the water, sex, and age of the fish (see Mariasingarayan et al., 2018).

Condition factor

In fisheries ecology, standard practices are used to determine the individual fish species' conditions based on the analysis of the length-weight data. Conditional factors are seen as quantitative parameters indicating the fish's state (size, maturity, spawning gonadal development, and the general well-being of the fish). According to Asadi et al. (2017), the heavier the fish at a given length, the better the condition due to suitable environmental conditions. The conditional factor, K, for the *E. affinis* was 1.94; for the *T. tonggol*, a value of 1.97 was recorded. The internal and external parameters were subject to conditional factors. Sex, age, gonadal maturity rates, and the fish's well-being can be correlated with internal factors. Additionally, the availability of food and the environmental conditions of the water in which the fish thrive can be used as external factors (Jalil et al., 2020). Conditional factors are based on the hypothesis that the heavier fish of a given length are in much better condition. According to the results, it was ≥ 1 for both species, showing an acceptable condition for both species in this area. However, for the current data, we could not identify which parameters, among those stated above, contributed to these findings. Hence, further analysis is needed.

Table 3. Parameters of length-weight relationship (a and b) and growth pattern for *E. affinis* and *T. tonggol* in different locations

Locality	Species	a	b	Growth type	References
Kuala Perlis	*E. affinis*	0.00000843	3.1173	(+) Allometric	Ahmad Adnan et al. (2015)
Northern Part of Peninsular Malaysia	*E. affinis*	0.000025	2.9335	(+) Allometric	Effarina et al. (2019)
West Nusa Tenggara, Indonesia	*E. affinis*	0.000011	3.114	(+) Allometric	Agustina et al. (2018)
Central Java Indonesia	*E. affinis*	0.1509	3.0513	(+) Allometric	Prasetyo et al. (2019)
Kuala Perlis	*T. tonggol*	0.0000103	3.09	(+) Allometric	Ahmad Adnan et al. (2015)
Northern of the Persian Gulf and Oman Sea, Iran	*T. tonggol*	0.00003	2.82	(-) Allometric	Yasemi et al. (2017)
Northern of the Persian Gulf and Oman Sea (Iran, Hormozgan Province)	*T. tonggol*	0.00002	2.87	(-) Allometric	Darvishi et al. (2018)

Conclusion

This paper provided information on the size distribution, LWRs, and K values for the *E. affinis* and *T. tonggol* in Sarawak. This fundamental biological information will be helpful for further population and stock assessment studies for fishery management in Sarawak. Both species exhibited a negative allometric growth pattern and were predominantly immature. Steps must be taken to ensure the sustainability of the species, for example, enlarged mesh size to give the fish a chance to spawn. Further studies are needed to investigate the effects of the parameters against the K and LWR values.

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