Assessing the Sustainable Fishery-based Industry in Malaysia Using the Analytic Hierarchy Process (AHP)

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Abstract. The concept of sustainability in the fishing-based industry is to reach and maintain the fishery at the maximum sustainable yield. This principle is important to ensure that the population of fish is maintained without compromising the ability of the future generations to meet their own needs. Inefficient sustainable management could cause the depletion of natural resources, pollutions and natural habitat loss in the future. Therefore, a good sustainable management for fishery should be emphasized so that future generations can enjoy what we have today. However, the fishery management is characterized by multiple conflicting attributes which are complicated to be inspected. In this paper, we would like to investigate the fishery management problem analytically by using the Analytic Hierarchy Process (AHP) method. Considering four criteria and thirteen sub-criteria influencing to the sustainability in the fishery-based industry, the AHP method will analyse and prioritize each criterion and sub-criterion. The BPMSG AHP Online System is used as the tool to process the collected data and the final results show that the protected species interaction (PSI) is the most important sub-criteria towards achieving the sustainable fisheries. This followed by the sub-criteria of profit (14.2%), employment (10.9%) and overfishing (8.90%). These four top sub-criteria must be monitored regularly as it can influence the sustainability of fishery-based industry. The other sub-criteria have their own priorities which should not be neglected as well.

1. Introduction
Malaysia which surrounded by the South China Sea and the Strait of Malacca has become one of the major fishing regions in Asia. This makes it one of the most popular fishing areas in the world which leads to the overfishing problems for certain targeted fish species. Besides overfishing, the sea pollution, bycatch, social awareness and policy are some of the factors that may lead to the diminishing of fish quantity and trigger some of the protected sea species. Since the fishing-based industry has been expanding day by day together with the advanced technology that improves the catches, it is believed that fisheries may be exhausted one day. According to the study from Food and Agriculture Organization (FAO), 25% of the fish stocks in the world are estimated to be at the unsustainable level today and the study shows that the sustainable level has been decreasing from 90% in 1974 to 68.6% in 2013 [1]. The term sustainability in fishing-based industry means to consistently maintain the catchment rate at the maximum sustainable yield (MSY). Sustainable fishing practices are essential to maintain the population of fish without adversely affect other species within the ecosystem. On top of that, it ensures that the future generations can continuously consume the seafood as we are today. Literature shows that several studies have been done in achieving the sustainable fisheries using various methods [2]–[4]. Fulton et. al [5] discussed the problems related to fisheries management, uncertainty in fisheries management and the impact of human behaviour towards the sustainable fisheries. Similarly,
Hobday et al. [6] discussed the internal and external factors towards the sustainable fisheries. On the other hand, Booshehrian et al. [7] analysed the data in the area of fisheries management using the Vismon tool. The simulation of Vismon system generates the outputs from the inputs that were running hundreds of Monte Carlo trials. Vismon is developed to be a user-friendly tool to the non-expert users of simulation software and statistical data analysis. Similar to the approach used by Booshehrian et al. [7], Punt et al. [8] evaluated the impact of environmental uncertainty and global climate change in achieving the fishery management purposes using the Monte Carlo simulation. In the other hand, Anh et al. [9] discussed three different possible management options to achieve the sustainable Vietnamese fisheries which are the fishing quality reduction, ecosystem-based approach and market-based management approach. Ecosystem-based approach has been adopted by Kenny et al. [10] in achieving the sustainable fisheries. They introduced another four sub-approaches of ecosystem-based approach; place-based management approaches, multi-species stock assessments, mixed fisheries management, identification and mapping of sensitive habitats, and assessing the significance of habitat impacts. Besides that, Boni et al. [11] assessed the sustainable management of coastal development plans in the Southern Italy using the PROMETHEE method. PROMETHEE is one of the multiple criteria decision aiding (MCDA) out-ranking methods which allows the analysis of complex problems involving sustainability criteria. Roux et al. [12] employed a productivity-susceptibility analysis by incorporating the traditional ecological knowledge from local fisheries for assessing the risk of sustainable fisheries management in Canada’s Arctic. This sustainability in fishery-based industry is a world worrisome issue that should be investigated seriously especially for the sustainability of our fishery-based industry. However, fishery management is a complex problem characterized by the multiple conflicting objectives and attributes.

Most of the previous researches of fisheries sustainability developed a simulation based approach and statistical analysis. However, the factors that influence the fisheries sustainability is multiple and complex. This complex problem can be solved by using the Analytic Hierarchy Process (AHP). The AHP method is systematically developed by Saaty [13] to intuitively arrange the complex problem into a hierarchical structure. Moreover, the AHP method is widely used to determine the relative importance in the multi-criteria decision problem and has been extensively studied and refined since then. The AHP method has been applied in various case studies such as the coastal erosion [14], selection of managers [15], sustainable supply chain [16] and etc. Bycatch and discards can cause biological overfishing and influence the marine ecosystems structure. Along with bycatch, there are four criteria and thirteen sub-criteria adopted from Leung et al. [3] that will be considered for this study. The four criteria included the biological, economic, social and politics perspectives. The aim of this study is to evaluate the sustainability of fishery-based industry in Malaysia using the Analytic Hierarchy Process (AHP) method. The rest of the paper is arranged as follows. Section 2 describes the AHP method. The application and results will be presented in the Section 3. Section 4 concludes the paper.

2. The AHP method
The method of AHP is generally described as follows:

*Step 1: Build the hierarchical structure*
Decompose the problem into a hierarchy of goal, criteria, sub-criteria and alternatives. Draw the decision problem into a hierarchy form.

*Step 2: Collect the data*
Collect data from experts corresponding to the hierarchical structure and based on the one to nine Saaty’s preference scale shown in table 1.

| Linguistic term | Intensity of important |
|-----------------|------------------------|
| Strongly disagree | 1 |
| Disagree | 3 |
| Slightly disagree | 5 |
| Slightly agree | 7 |
| Agree | 9 |

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Equally important & 1 \\
Moderately more important & 3 \\
Strongly more important & 5 \\
Very strong more important & 7 \\
Extremely more important & 9 \\
Intermediate more important & 2, 4, 6, 8 \\

**Step 3: Construct the pair-wise comparison matrix**
Transfer the pairwise comparisons values of the criteria into a square matrix. The diagonal elements of the matrix are always one which reflecting the equally important when comparing the criterion by itself. The evaluation matrix is generally as below.

$$A = \begin{bmatrix}
1 & a_{12} & \Lambda & a_{1n} \\
\frac{1}{a_{12}} & 1 & \Lambda & a_{2n} \\
\frac{1}{M} & \frac{1}{M} & 1 & M \\
\frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \Lambda & 1 \\
\end{bmatrix}$$

**Step 4: Find the priorities of each criterion**
Find the normalized priorities of each criterion by using the row geometric mean method (RGMM). This approach is used because of its simplicity, easy to find the maximum eigenvalue and the ability to reduce the inconsistency value of judgments [17]. The RGMM approach is defined as below:

$$r_i = \exp \left[ \frac{1}{N} \sum_{j=1}^{N} \ln (a_{ij}) \right] = \left( \prod_{j=1}^{N} a_{ij} \right)$$  \hspace{1cm} (1)

$$p_i = \frac{r_i}{\sum_{i=1}^{N} r_i}$$  \hspace{1cm} (2)

where $p_i$ is the priorities of the criteria.

**Step 5: Calculate the consistency ratio**
The consistency ratios (CR) are calculated to check whether the result is consistent or not. If the CR fails to achieve the required level which is below 0.1, the pairwise comparison need to be revised by the experts until the consistency ratio is satisfied. The CR can be calculated as below:

$$CR = \frac{CI}{RI}$$  \hspace{1cm} (3)

where

$$CI = \left( \frac{\lambda_{\text{max}} - N}{(N - 1)} \right)$$ and $$\lambda_{\text{max}} = \sum_{j=1}^{N} p_j a_{ij}$$  \hspace{1cm} (4)

The random index (RI) is showed as table 2.

| n  | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| RI | 0   | 0.58| 0.90| 1.12| 1.24| 1.32| 1.41| 1.45|     |
Step 6: Aggregation

Aggregated of individual judgement (AIJ) approach is applied to form an aggregated decision matrix $C_{ij}$ which indicates the group result. In this research, $C_{ij}$ is calculated using weight geometric mean (WGM) method and by considering the individual experts’ weights, $w_k$ are all equal. $C_{ij}$ is calculated using WGM method as shown as follows:

$$C_{ij} = \exp \left[ \frac{\sum_{k=1}^{N} w_k \ln A_{ij(k)}}{\sum_{k=1}^{N} w_k} \right]$$

(5)

where $w_k$ is the weight of $k^{th}$ expert and $A_{ij(k)}$ is the pairwise comparison matrix of $k^{th}$ expert.

Step 7: Obtain the global priorities

The global priorities, $P_G$ can be obtained by multiplying the priorities of criteria $P_{i\text{(criteria)}}$ with the priorities of sub-criteria $P_{i\text{(sub-criteria)}},$ as equation below:

$$P_G = P_{i\text{(criteria)}} \times P_{i\text{(sub-criteria)}}$$

(6)

3. Application and Results

In this section, the factors contributing to fishery management issue are assessed using the AHP method. The evaluation is analysed using the BPMSG AHP Online System where all the computations has been built up in that system. Therefore, we will only show the results based on this system without showing the computations behind them. Five experts in the fishery industry have been invited to provide their opinions and judgments on the factors contributing to the unsustainability of fishery-based industry. Table 3 shows the background of the five experts.

| Expert | Name | Expertise | Age | Working experience (years) |
|--------|------|-----------|-----|----------------------------|
| 1      | Lee Lian Seng | Salted fish wholesaler | 56 | 39 |
| 2      | Lee Lean Ung | Fishmonger | 60 | 43 |
| 3      | Teh Yi Hen | Worker in salted fish factory | 23 | 2 |
| 4      | Teoh Wei Xun | Retailer and Wholesaler in fish market | 29 | 7 |
| 5      | Tan Zhi Lun | Wholesaler in fish market | 20 | 5 |

Table 4 shows the criteria and sub-criteria that are required for the measurement of sustainability in fishing-based industry in Malaysia.

| Criteria | Sub-criteria | Description |
|----------|--------------|-------------|
| Biological | Maximum sustainable yield (MSY) | - catch rate year after year where the fish stock will remain viable or ‘healthy’ in the long run. -minimize overfishing |
Overfishing
Bycatch
Protected species interaction (PSI)

Economic
Employment
Profit

Social
Community lifestyle
Accessibility
Social bycatch
Protected species interactions (PSI)
Gear conflict

Political
Public acceptance
Resistance

Step 1: Build the hierarchical structure
After the criteria and sub-criteria are determined, the problem is decomposed into a hierarchical structure which consists of goal, criteria, sub-criteria and alternatives. Figure 1 shows the hierarchical model of sustainable fishery-based industry in Malaysia.

Economic
Employment
Profit

Social
Community lifestyle
Accessibility
Social bycatch
Protected species interactions (PSI)
Gear conflict

Political
Public acceptance
Resistance

• Maximum sustainable yield (MSY)
• Overfishing
• Bycatch
• Protected species interaction (PSI)

• Employment
• Profit

• Community lifestyle
• Accessibility
• Social bycatch
• Protected species interaction (PSI)
• Gear conflict

Figure 1. The hierarchical structure of the sustainable fishery-based industry

Then multiply the local ratings by the weights of the criteria and aggregated to get the global ratings.

Step 2: Collect the data
Collect data from experts corresponding to the hierarchical structure and based on the one to nine Saaty’s preference scale shown in table 1.
Step 3: Construct the pair-wise comparison matrix

The collected data by questionnaire are inserted into the BPMSG AHP Online System. Figure 2 shows the pairwise comparison evaluation value between criteria provided by one of the experts, Mr. Lee Lian Seng. The pairwise comparison between sub-criteria can be done the same way and not shown here due to the page limitation.

![Pairwise comparison matrix](image)

**Figure 2.** Pairwise comparison between criteria provided by expert 1

Transfer the pairwise comparisons values of the criteria into a square matrix. From figure 2, the evaluation matrix is formed as below:

\[
A = \begin{pmatrix}
1 & 3 & \frac{1}{3} & 5 \\
\frac{1}{3} & 1 & \frac{1}{5} & 3 \\
3 & 5 & 1 & 5 \\
\frac{1}{5} & \frac{1}{3} & \frac{1}{5} & 1 \\
\end{pmatrix}
\]

Step 4: Find the priorities of each criterion

By using equations (1) and (2), the BPMSG AHP Online System obtained the priorities of each criterion. Table 5 shows the priorities of the experts and consistency ratio (CR) based on the criteria and sub-criteria.

| Participants | Biological | Economic | Social | Political | CR  |
|--------------|------------|----------|--------|-----------|-----|
| Expert 1     | 27.1%      | 12.2%    | 54.4%  | 6.4%      | 7.3%|
| Expert 2     | 9.7%       | 64.3%    | 20.9%  | 5.1%      | 8.8%|
| Expert 3     | 27.9%      | 52.5%    | 5.6%   | 13.9%     | 5.1%|
| Expert 4     | 64.0%      | 8.0%     | 10.4%  | 17.6%     | 6.0%|
| Expert 5     | 56.9%      | 7.7%     | 31.3%  | 4.1%      | 9.0%|
Step 5: Calculate the consistency ratio

By using equations (3) and (4), the BPMSG AHP Online System calculated the CR value as shown in the last column of table 5. Since all the obtained CR value is less than 10%, which is the acceptable percentage. The CR value indicates the consistency of experts in making judgment. If the CR value is higher than 10%, we need to revised the experts’ evaluation until the acceptable CR is obtained.

Step 6: Aggregation

The aggregation of individual judgement (AIJ) is conducted using weight geometric mean (WGM) method as in equation (5) and by considering the individual expert’s weight are equal which is \( w_k = 0.2 \). Based on the individual experts’ evaluation matrices, the computation to get an aggregated group priorities is as below:

\[
C_{ij} = e^{0.2 \ln \begin{bmatrix}
0.2 & 0.2 & 0.2 & 0.2 & 0.2 \\
0.2 & 0.2 & 0.2 & 0.2 & 0.2 \\
0.2 & 0.2 & 0.2 & 0.2 & 0.2 \\
0.2 & 0.2 & 0.2 & 0.2 & 0.2 \\
0.2 & 0.2 & 0.2 & 0.2 & 0.2 \\
\end{bmatrix}}
\]

\[
= \begin{bmatrix}
1.8001 & 0.4045 & 40.5% \\
1.1161 & 0.2508 & 25.1% \\
4.4501 & 1.0702 & 24.1% \\
0.4637 & 0.1042 & 10.4% \\
\end{bmatrix}
\]

\[
r_i = \begin{bmatrix}
1.8001 & 0.4045 & 40.5% \\
1.1161 & 0.2508 & 25.1% \\
4.4501 & 1.0702 & 24.1% \\
0.4637 & 0.1042 & 10.4% \\
\end{bmatrix}^{-1}
\]

\[
p_i = \frac{\sum_{i=1}^{N} r_i}{N} = \begin{bmatrix}
40.5% \\
25.1% \\
24.1% \\
10.4% \\
\end{bmatrix}
\]

Consistency ratio is calculated as below:
\[ \lambda_{\text{max}} = 0.4045 \left( 1 + 0.6776 + 0.5818 + 0.2416 \right) + 0.2508 \left( 1.4758 + 1 + 0.4367 \right) + 0.2405 \left( 1.7188 + 1 + 0.4434 \right) + 0.1042 \left( 4.1392 + 2.2901 + 2.2551 + 1 \right) \\
= 4.0030 \\
CI = \frac{\lambda_{\text{max}} - N}{N - 1} = \frac{4.0030 - 4}{4 - 1} = 0.001 \\
CR = \frac{CI}{RI} = \frac{0.001}{0.9} = 0.0011 = 0.1\% \\

The aggregated priorities of criteria is summarized as in figure 3 below.

![Figure 3](image)

**Figure 3.** Aggregated priorities of criteria

**Step 7: Obtain the global priorities**

Based on equation (6), the global priorities of sub-criteria is shown in the table 6 below.

| Criteria | Relative priorities | Sub-criteria | Relative priorities | Global priorities |
|----------|---------------------|--------------|---------------------|-------------------|
| Biological | 0.405 | MSY | 0.119 | 0.048 |
|           |       | Overfishing | 0.22 | 0.089 |
|           |       | Bycatch | 0.141 | 0.057 |
|           |       | PSI | 0.52 | 0.211 |
| Economic  | 0.251 | Employment | 0.433 | 0.109 |
|           |       | Profit | 0.567 | 0.142 |
| Social    | 0.241 | Community lifestyle | 0.052 | 0.013 |
|           |       | Access | 0.257 | 0.062 |
|           |       | Social bycatch | 0.301 | 0.073 |
|           |       | Social PSI | 0.273 | 0.065 |
From table 5, the global priorities show the importance of each sub-criterion in effecting the sustainable fishery-based industry in Malaysia. The higher the global priorities, the higher the importance of that sub-criterion towards the fishery sustainability. The global priorities of sub-criteria are presented in a chart form as figure below.

Figure 4. Global priorities of group result.

Based on the information in figure 4, the PSI is obviously the highest priority (21.1%) in achieving a sustainable fishery-based industry in Malaysia. This followed by profit (14.2%), employment (10.9%) and overfishing (8.90%) sub-criteria that contribute to the unsustainable fishery-based industry in Malaysia. These four sub-criteria must be handled carefully so that the sustainable fishery-based industry in Malaysia can be achieved. The least important sub-criterion is community lifestyle and values with only 1.3%. This indicates that the sub-criteria of community lifestyle and values is not affecting the goal. The rest of the sub-criteria have their own priorities which should not be neglected as well.

4. Conclusions
The study was conducted to assess the efficiency and sustainability of fishery-based industry in Malaysia. The collected data from five experts in the fishery field are analysed using the AHP method. The results obtained with the help of the BPMSG AHP Online System show all the global priorities of thirteen sub-criteria. The aggregated judgement of the experts reveals that PSI is the most important sub-criteria with 21.1% of global priorities. In addition, the relative weights of criteria show that the biological criteria are the most important criteria compared to the other criteria. The priorities of criteria followed by economic, social and political criteria. The results from this study can be very useful to the fisheries stakeholders to take any possible actions ahead in reaching the sustainable fishery-based industry. The AHP model has successfully been applied in the fisheries management problem. The AHP method is recommended to be employed for getting the global priorities of any complicated problems involving multiple criteria.
5. References

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