Developing a decision support system for sustainable cage aquaculture

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Abstract

A decision support system to assist cage aquaculture managers is presented. The system enables managers to perform four essential tasks: (i) site classification, (ii) site selection, (iii) holding capacity determination, and (iv) economic appraisal of an aquaculture farm at a given site. Based on measurements of water and substrate qualities, hydrometeorology and socioeconomic factors, a cage aquaculture site is classified into three categories – poor, medium, and good. With this information, the AHP (analytical hierarchy process) tool is used to evaluate the best site from several alternatives. A simplified version of the Modelling-On growing-Monitoring (MOM), SMOM, is developed and applied to determine how much fish can be grown on site without harming the environment. The simplified model has been calibrated against MOM, compared with other carrying capacity models and validated with farm data. A break-even point–price and return on investment (ROI) are calculated using cage-holding density and volume, mean fish weight at harvest, feed conversion ratio (FCR), survival rate of seed, costs of feed, seed and cages, the interest rate on borrowed funds and the fish price. All model components are integrated seamlessly into a user-friendly interface implemented in Java® called CADS_TOOL (Cage Aquaculture Decision Support Tool). The program with a user’s guide is freely available.

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1. Introduction

Cage aquaculture is expanding worldwide, with the cage culture of high value finfish the fastest growing sector (Tacon and Halwart, 2007). Delgado et al. (2003) predict that fish consumption in developing countries will increase by 57%, from 62.7 million metric tons in 1997 to 98.6 million in 2020, and cage aquaculture is expected to play a major role in meeting this demand (Tacon and Halwart, 2007). In Asia, over 95% of marine finfish aquaculture is in cages, and production has steadily increased in the region, to reach 1.7 million tons in 2004 (De Silva and Phillips, 2007). With such a rapid increase in sea cage aquaculture, there is an urgent need to develop planning tools that can be applied to the predominately tropical environments of Asia, so that the high level of production can be managed in an environmentally sustainable manner.

There are many forms of impact resulting from cage aquaculture that could threaten its sustainability. For instance, the settling of wastes of high organic content from uneaten feed and faeces favours the growth of bacteria on the seabed underneath the cages. Decomposition of this organic material by bacteria consumes oxygen and can cause hypoxia in bottom waters and sediment (Aure and Stigebrandt, 1990; Nilsson and Rosenberg, 2000; Gray et al., 2002; Holmer et al., 2003). In addition, accumulation of sulphides in the sediment pore water affects benthic organisms, which in turn, may cause the loss of fauna and seagrasses (Cancemi et al., 2003; Greve et al., 2003; Bongiorni et al., 2005; P-Martini et al., 2006). Discharge of phosphorus and nitrogen compounds from the farms might also change the nutrient ratio nearby favouring local algal blooms and eutrophication (Aure and Stigebrandt, 1990; Maldonado et al., 2005; Buschmann et al., 2006; Mente et al., 2006; Pitta et al., 2006; Sarà, 2007). In the tropics, eutrophication originating from fish farms can threaten coral survival (Loya et al., 2004; Villanueva et al., 2006).

A broad range of aquaculture decision support systems are in existence. Some of them have taken environmental impacts into account, such as those for selecting and licensing aquaculture sites (Silvert, 1994a,b; Ervik et al., 1997; Stagnitti, 1997; Stagnitti and Austin, 1998; Hargrave, 2002; Stigebrandt et al., 2004; Moccia and Reid, 2007) and for planning nutrient removal (Vezzulli et al., 2006). Others are used for designing aquaculture facilities (Ernst et al., 2000), managing hatchery production.
forecasting aquaculture products (Xiaoshuan et al., 2005), facilitating aquaculture research and management (Bourke et al., 1993), and evaluating economic impact (Bolte et al., 2000).

In this study we develop a decision support tool for cage aquaculture. It covers various activities starting from classifying a site, selecting the best site from several site alternatives, calculating a sustainable holding density from a chosen site, and finally performing an economic appraisal of a site. Each activity is formed into a specific module and all modules are integrated into a Java program called CADS_TOOL (Cage Aquaculture Decision Support Tool).

2. Decision support modules

The decision support tool developed here is divided into four modules. The modules are (i) site classification; (ii) site selection; (iii) holding density; and (iv) economic appraisal. Each module is described below.

2.1. Site classification

This module has the purpose of classifying a site into poor, medium and good suitability classes. Each class is determined by a set of criteria and sub-criteria adopted from the literature (NACA, 1989; Nilsson and Rosenberg, 1997; UNESCO, 2000; APEC/SEAFDEC, 2001; Håkansson and Boulion, 2001; Wildish et al., 2001; Frankic, 2003). The relative importance (RI) of criteria and sub-criteria can be preset. A questionnaire described in Appendix A collects the necessary information from experts. In the example described in Table 1, ‘hydrometeorology’ is the most highly rated criterion, followed by ‘water quality’, ‘substrate quality’, and ‘socioeconomic’ criteria. Similarly, amongst sub-criteria under ‘hydrometeorology’, ‘current’ is the highest followed by ‘water depth’, and ‘significant wave height’ sub-criteria.

The result of this module is shown in Fig. 1. The user types in values measured from a site and the classification score for the site is calculated. For this example, the site is mostly suitable (‘Good’) except for few parameters: secchi disk, wave height and proximity to market.

2.2. Site selection

The objective of this module is to determine a suitability score for each potential site. The scores are ‘good’, ‘medium’, and ‘poor’. The score is determined by applying a multi-criterion decision analysis tool called AHP (analytical hierarchy process) developed by Saaty (1980). This method has been previously applied to environmental studies (Karatzas et al., 2003; Thirumalaivasan et al., 2003; Uddameri, 2003; Moffett et al., 2005; Yatsalo et al., 2007; Ying et al., 2007; Brüggemann et al., 2008), engineering education and designs (Drake, 1998; Wong and Li, 2008), project management (Al-Harbi, 2001), fisheries management (Mardle and Pascoe, 2004), aquaculture site selection (Salam et al., 2005), bridge construction (Salem and Miller, 2006), and contaminated sediment studies (Yatsalo et al., 2007). The AHP inputs RI scores given in Table 1 for criteria and sub-criteria and outputs the weights of criteria/sub-criteria and the consistency ratio. This ratio fulfills the so called transitivity property, i.e. if criterion A is better than criterion B, and criterion B is better than criterion C, then criterion A should be better than criterion C (Mardle and Pascoe, 2004). Saaty (1980) invented a heuristic rule to check this property (Saaty, 1980), i.e. the ratio should not exceed 0.1. If it does, the value of the relative importance in Table 1 should be changed. The AHP procedures are fully described in Appendix A.

The AHP procedure is first performed to obtain a pair-wise matrix of the four criteria: water quality, substrate quality, hydrometeorology and socioeconomic data. The results are shown in Table 2, and confirm the result that ‘hydrometeorology’ is the most important criterion, i.e. it has the highest weight. The relative importance does not need to be changed since the consistency ratio is below 0.1.

The AHP procedure is also performed for all sub-criteria under each criterion to obtain their sub-criteria weights. Total weight for each sub-criterion is obtained by multiplying each of these sub-criteria weights by the weight of their respective criteria. Performing an AHP analysis for sub-criteria under the ‘water quality’ criterion is taken as an example. Here the sub-criteria are NH4, DO, and secchi depth. The analysis obtains weights of 0.4934, 0.3108, and 0.1958, respectively. In this case, the consistency ratio is found to be 0.0516. By multiplying these weights with that of water quality of 0.2683 as in Table 2, the final weights for these sub-criteria are found to be 0.1413, 0.0890, and 0.0561, respectively. Final weights of all sub-criteria are presented in Table 3. The total weight is found to be 1, and the first three important variables are current, water depth and NH4.

Now, we are in a position to determine the score of each potential site. The total score for each site is calculated by multiplying the final weight and suitability class for each sub-criterion and adding the results. The suitability class for the site is automatically entered from the Site Classification tab. Fig. 2 shows the overall result, with the site scored as of ‘medium’ suitability.

2.3. Holding density

The goal of this module is to calculate the maximum permissible fish biomass in a cage. Given a set of environmental conditions, feeding regimes, and sea cage arrangements, what monthly maximum production of fish can be sustained? A solution to this question is provided by the MOM (Modelling-On growing-Monitoring) method developed by Ervik et al. (1997), Hansen et al. (2001), and Stigebrandt et al. (2004). The original version of the MOM model needs 28 inputs. We ran 100 simulations in which we varied each of these inputs as depicted in Table 4 to calculate holding density, i.e. holding capacity divided by cage volume. A stepwise multivariate regression was then performed to select the most pertinent variables. The chosen input variable(s) are based on
a significant level of 0.95 (Draper and Smith, 1981). The resulting stepwise regression model, called SMOM (simplified MOM), for calculating holding density (in kg/m³) is

\[
HD = 0.002X1 - 0.018X2 + 0.004X3 - 0.012X4 - 0.081X5 \\
+ 0.075X6 - 0.008X7 + 0.008X8 - 0.004X9 + 0.096 \\
(1)
\]

where:

- \(X1\) = water flow at the surface (\(\beta1 = 0.487\));
- \(X2\) = critical oxygen concentration in the cage (\(\beta2 = -0.375\));
- \(X3\) = flow variance (\(\beta3 = 0.34\));
- \(X4\) = number of cage rows (\(\beta4 = -0.258\));
- \(X5\) = ammonium concentration in the cage (\(\beta5 = -0.234\));
- \(X6\) = critical ammonium concentrations in the cage (\(\beta6 = 0.173\));
- \(X7\) = food conversion ratio (\(\beta7 = -0.166\));
- \(X8\) = critical oxygen concentration at the seabed (\(\beta8 = 0.155\));
- \(X9\) = cage length (\(\beta9 = -0.151\)).

Standardized coefficients \(\beta\)’s measuring relative importance for each selected variable in (1) is also given as above. The SMOM model has an adjusted \(R^2\) and standard error of estimate of 0.59 and a holding density of 20 kg/m³. Fig. 3 gives result of implementing SMOM in CADS TOOL. Note that we added another variable called “percentage dry matter” to account for the type of feed given. Pellets and trash fish are assigned a dry matter content of 90% and 25%, respectively (Boyd et al., 2007), but this can be adjusted for direct measurements of dry matter content where they are available. The variable \(X4\) applies when cages are arranged as a group or array. In the case of a farm with isolated (rather than connected) cages (e.g. “polar circle” designs), each cage should be treated as an isolated
cage, since it has its own flow and waste dispersal regimes, and the number of row should be set to 1.

Note that CADS_TOOL includes other models for calculating carrying capacity: two oxygen budget models for marine cages (Tookwinas et al., 2004; Hanafi et al., 2006), and a phosphorus budget model for fresh water cages (Pulatsu, 2003).

2.4. Economic appraisal

The last module is an economic appraisal of an aquaculture practice at the chosen site. Given a holding density, cage volume, survival rate of fish seed, mean fish weight at harvest, FCR, cost of seed, feed, and cage (for construction and operation), interest rate on borrowed funds, and fish price at harvest, the break-even price (BEP) and the return on investment (ROI in percent) are calculated. The formulae for both measures are derived in Appendix C. An example is presented in Fig. 4. Here we use Indonesian currency, the Rupiah (Rp.). Based on data provided by a user, the fish has to be sold at the price of Rp. 12,025.71 to achieve the break-even point. Accordingly, if the fish is sold at Rp. 70,000, the farmer will obtain a return about 4 times the original investment.

3. Discussion and conclusion

A decision support tool for aquaculture called CADS_TOOL has been developed for application to the rapidly growing sea cage aquaculture industry in SE Asia and is available free of charge from the Australian Institute of Marine Science website (http://www.aims.gov.au). Tools for site classification, site selection,
determination of holding density and economic appraisal are assembled into modules integrated into a Java program that can be run on any computer supporting the Java Runtime Environment. The modular form has the advantage that modifications can be easily made. We have endeavoured to make CADS_TOOL easily available and easy to implement, but users should interpret model output considering the behaviour and validation of the model with regard to suitability classification and the estimation of holding capacity, as discussed below.

### 3.1. Suitability classification

There is a circumstance when CADS_TOOL classifies a site as unsuitable only by considering a single parameter, i.e. water flow of few meters per second. We can implement such a case by performing a check on whether or not an input value for a parameter is still within its class range. If the value does not belong to any of the class, the site is classified as an unsuitable site for aquaculture.

There are also potential modifications in the classification scheme. For instance, changes in the suitability classification criteria and sub-criteria could include other factors such as benthic diversity, habitat quality and abundance (Nilsson and Rosenberg, 1997; UNESCO, 2000), sediment quality (Wildish et al., 2001; Viaroli et al., 2004), water retention times (Viaroli et al., 2004), water quality (Bricker et al., 2003), biophysical criteria (Nath et al., 2003), and nutrient thresholds (Devlin et al., 2007).

### 3.2. Holding density

Formula 1 of SMOM shows that holding density increases under the following conditions: (i) in strong water flows ($X_1$ and $X_3$) that improve waste removal; (ii) when critical ammonium concentrations are higher, i.e. higher tolerance by cultured fish ($X_6$); and (iii) when critical oxygen concentration at the seabed are higher ($X_8$). Having stronger flows and higher critical ammonium concentrations to obtain higher holding density is in agreement with MOM formulations, i.e. formula 13 and 14 of MOM (Stigebrandt et al., 2004). Higher critical bottom oxygen, however, should result in lower holding density according to the MOM formulae, i.e. Eq. (8) of Stigebrandt et al., (2004). In this case, $X_8$ is spurious.

On the other hand, holding density is negatively correlated with the other five factors: (i) critical oxygen in a cage, i.e. the minimum oxygen concentration allowable for cultured fish to grow ($X_2$); (ii) ammonium concentration ($X_5$); (iii) FCR ($X_7$); (iv) larger farm size ($X_4$ and $X_9$). Farm size is determined by the number of cage rows ($X_4$) and the cage length ($X_9$), and is negatively correlated with holding density because more wastes are being released into the environment.

#### 3.2.1. How to calibrate SMOM against the original MOM?

We performed a curve fitting exercise to calibrate SMOM against MOM holding densities. In this case both linear and quadratic functions were used (Fig. 5). The linear fit results in a few spurious points, i.e. holding density is less than 0 and an error estimate of...
21.4 kg/m³ while those of the quadratic fit has less error, i.e. 20 kg/m³. As a consequence, the uncorrected holding density \( HD \) (formulae 1) should be corrected as:

\[
\text{HD corrected} = \frac{1}{10} \times 11.0822HD^2 + 0.3312HD + 0.0009.
\]  

(2)

### 3.2.2. How does SMOM compare to other models?

Two other carrying capacity models for sea cages are implemented in CADS_TOOL, i.e. the cage-scale model of Tookwinas et al. (2004) and the bay-scale model of Hanafi et al., (2006). A direct comparison of results is only possible using the former.

The Tookwinas et al., (2004) model calculates fish biomass that can be grown in a cage array, and needs oxygen inflow and outflow around cages, oxygen consumptions by cultured fish, sediment and water column, water flow, cage area and cage depth. Let us calculate carrying capacity based on the following information taken from Tookwinas et al. (2004): oxygen inflow and outflow around cages (in mg/l) are 5.24 and 3.4, respectively; oxygen consumptions by cultured fish, sediment and water column are 0.25 g oxygen/kg fish/h, 211 mg oxygen/m²/h, and 0.15 mg oxygen/l/h, respectively; water flow of 90 cm/s; cage area and depth of 16 m² and 2.7 m, respectively. In this case the Tookwinas model estimates a holding density (cultured fish, i.e. grouper biomass divided by cage volume) of 40.11 kg/m³. SMOM also produces a holding density of 40.4 kg/m³ under the following conditions: surface current and current variation of 10 and 5 cm/s, respectively; critical oxygen in cage and at seabed of 3 and 2 mg/l, respectively; ammonium in cage and its critical value of 0.2 and 0.3 mg/l, respectively; FCR of 3, cage length and cage row of 4 m and 1, respectively. Changing the surface current to 90 cm/s while keeping all other parameters the same, however, results in a much higher holding density of 200.4 kg/m³.

### 3.2.3. How do SMOM estimates compare the observed holding density at the farms?

During our program for disseminating CADS_TOOL from July to August 2008 in Indonesia, we visited and managed to collect farm data from Lampung, Aceh and Batam provinces of Indonesia. The parameters (either measured or estimated) and observed holding density from three cage farmers CF1, CF2 and CF3 with their name retained, are described in Table 5. Estimates resulting from SMOM calculations based on these input parameters are also presented in Table 5.

Beside the models already implemented in CADS_TOOL, there are other carrying capacity models that could also be included in
future versions. They are the environmental capacity models for marine cages (Sumagaysay-Chavoso et al., 2004; Yokoyama et al., 2007) and fresh water cages (Abery et al., 2005).

Acknowledgement

The development of the simplified MOM model and its application to the aquaculture of tropical finfish is part of the ACIAR project FIS/2003/027 Planning tools for environmentally sustainable finfish cage culture in Indonesia and northern Australia. We thank H. Stigebrandt for helping us to run MOM through the Internet from the ANCYLUS website. Halmar Halide would also like to express his gratitude to the Australian Government for the ACIAR post-doctoral fellowship.

Appendix A. Survey: cage suitability criteria (adopted from Salem and Miller, 2006)

Purpose: determining weight for each criterion and sub-criterion using analytical hierarchy process.

A.1. What is the relative importance that should be given to the following criteria for a sustainable aquaculture cage project?

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Weight [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water quality</td>
<td>30</td>
</tr>
<tr>
<td>Substrate quality (sediment below cages)</td>
<td>35</td>
</tr>
<tr>
<td>Hydrometeorology</td>
<td>35</td>
</tr>
<tr>
<td>Socioeconomic</td>
<td>15</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>

A.2. The following sub-criteria have been identified for each of the above criteria. Please rate the relative importance of each sub-criterion

A.2.1. Water quality

<table>
<thead>
<tr>
<th>Sub-criterion</th>
<th>Weight [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissolved oxygen (DO)</td>
<td>15</td>
</tr>
<tr>
<td>Ammonium (NH₄)</td>
<td>15</td>
</tr>
<tr>
<td>Water depth</td>
<td>15</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>

A.2.2. Substrate quality

<table>
<thead>
<tr>
<th>Sub-criterion</th>
<th>Weight [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Textures</td>
<td>30</td>
</tr>
<tr>
<td>Redox potential</td>
<td>25</td>
</tr>
<tr>
<td>Organic matter</td>
<td>25</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>

A.2.3. Hydrometeorology

<table>
<thead>
<tr>
<th>Sub-criterion</th>
<th>Weight [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>25</td>
</tr>
<tr>
<td>Significant wave height</td>
<td>25</td>
</tr>
<tr>
<td>Water depth</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>

A.2.4. Socioeconomics

<table>
<thead>
<tr>
<th>Sub-criterion</th>
<th>Weight [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market</td>
<td>25</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>25</td>
</tr>
<tr>
<td>Regulations</td>
<td>25</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 5

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CF1</th>
<th>CF2</th>
<th>CF3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface current [cm/s]</td>
<td>30</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Current standard deviation [cm/s]**</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Critical oxygen in cage [mg/l]**</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Critical bottom oxygen [mg/l]**</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Ammonium in cage [mg/l]**</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>% Dry matter of feed</td>
<td>25</td>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>Food conversion ratio (FCR)</td>
<td>8</td>
<td>6.9</td>
<td>10</td>
</tr>
<tr>
<td>Farm length [m]</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Cage rows</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Observed holding density [kg/m³]</td>
<td>25</td>
<td>25</td>
<td>45</td>
</tr>
<tr>
<td>SMOM calculated holding density [kg/m³]</td>
<td>30.22</td>
<td>26.67</td>
<td>53.2</td>
</tr>
</tbody>
</table>

Parameters marked with an asterisk ‘*’ are estimated.

Appendix B. AHP procedures

B.1. Converting the relative importance RI into pair-wise matrix elements M

Suppose we have two relative importance values of c₁ and c₂. We then take the ratio of these values. There are two conditions to be considered.

B.1.1. c₁ > c₂

\[
\text{ratio1} = \frac{c_1}{c_2}
\]

if \( \text{ratio1} = 1 \) then \( m = 1 \)

if \( 1 < \text{ratio1} \leq 2 \) then \( m = 2 \)

if \( 2 < \text{ratio1} \leq 3 \) then \( m = 3 \)

if \( 3 < \text{ratio1} \leq 4 \) then \( m = 4 \)

otherwise \( m = 5 \).

B.1.2. c₁ < c₂

\[
\text{ratio2} = \frac{c_1}{c_2}
\]

if \( \text{ratio2} = 1 \) then \( m = 1 \)

if \( 1 < \text{ratio2} \leq 2 \) then \( m = 1/2 \)

if \( 2 < \text{ratio2} \leq 3 \) then \( m = 1/3 \)

if \( 3 < \text{ratio2} \leq 4 \) then \( m = 1/4 \)

otherwise \( m = 1/5 \).

B.2. Interpreting the pair-wise matrix elements M in terms of Saaty’s intensity of importance measures (Al-Harbi, 2001)

<table>
<thead>
<tr>
<th>M</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equally preferred</td>
</tr>
<tr>
<td>2</td>
<td>Equally to moderately preferred</td>
</tr>
<tr>
<td>3</td>
<td>Moderately preferred</td>
</tr>
<tr>
<td>4</td>
<td>Moderately to strongly preferred</td>
</tr>
<tr>
<td>5</td>
<td>Strongly preferred</td>
</tr>
</tbody>
</table>

B.3. Calculating eigen value and consistency ratio

Let the pair-wise matrix is represented by a matrix \( M \) of order \( n \).

\[
M = (m_{ij}).
\]

This matrix is also a reciprocal matrix, i.e.
$m_{ij} = m_{ji}$. \hfill (B.3.2)

The eigen value problem is able to derived from this matrix (Saaty, 1980; Chandran et al., 2005) and has the form:

$$(M - I)l = 0,$$ \hfill (B.3.3)

where $I$ is the unity matrix.

The eigen values, i.e., the weights, and the maximum eigen value $\lambda_{\text{max}}$ is obtained through a MATLAB subroutine called 'EIG' (Scott, 2007).

Consistency index $CI = (\lambda_{\text{max}} - n)/(n - 1)$. \hfill (B.3.4)

Random index $Rdi = 0.5$ (for $n = 3$) and $0.9$ (for $n = 4$).

Consistency ratio $CR = CI/Rdi$. \hfill (B.3.5)

Appendix C. Economic appraisal formulæ

Given a holding density (HD in kg/m²), cage volume (CV in m³), survival rate of fish seed (SR in percent), mean fish weight at harvest (FW in kg), FCR (food conversion ratio), seed cost (SC), feed cost (FC), cage cost (CC) for construction and operation, interest rate (IR in percent), and fish price (FP), the revenue (REV) and profit (PRO) are calculated as:

- Break-even price (BEP) is calculated as:

$$\text{BEP} = \frac{\text{TC}}{\text{WH}}.$$ \hfill (C8)

Now, if the fish is sold at a price of FP, the revenue (REV) and profit (PRO) obtained is:

$$\text{REV} = \text{FP} \times \text{WH},$$ \hfill (C9)

and

$$\text{PRO} = \text{REV} - \text{TC}.$$ \hfill (C10)

Consistency index $CI = (\lambda_{\text{max}} - n)/(n - 1)$. \hfill (B.3.4)

Random index $Rdi = 0.5$ (for $n = 3$) and $0.9$ (for $n = 4$).

Consistency ratio $CR = CI/Rdi$. \hfill (B.3.5)

References


