Estimation of Maximum Sustainable Yield (MSY) for Sustainable Fish Catch

N A Jamaluddin, S A Sheikh Hussin¹, Z Zahid, S S Mohd Khairi

¹Department of Statistics and Decision Sciences, Universiti Teknologi MARA, 40450, Shah Alam, Selangor, Malaysia.

E-mail: sitiaida@tmsk.uitm.edu.my

Abstract. Fishery is an entity engage with fish catch on the sea ground by fisherman. The fish catch in Peninsular Malaysia has declined by more than 90% since 1960s. Thus, it is important to know the maximum sustainable yield in order to overcome the decreasing number of fish and estimate the number of fishes that can be caught from the sea without endangering the fish population. The main purpose of this study is to calculate the maximum sustainable yield of fish catch in Terengganu by applying Bayesian surplus method. The results show that the amount of maximum sustainable yield is 100100 tons with 205700 fishing trips per year. Based on the value of maximum sustainable yield and optimum number of fishing trip, the current fish stocks have been overfished from year 2000 to 2008 since the fish catch and fishing effort for the year exceeded the optimum value. As a result, the numbers of fish catch for the year 2009 to 2016 was lower even though the fisherman put higher fishing effort.

1. Introduction
The fisheries sector in Malaysia is an extremely important sector and plays a vital role in the national economy. There are three main subsectors which are marine public water bodies, aquaculture and capture fisheries. This study focuses on marine capture fisheries. In 2010, the fisheries sector contributed 1.3% to the nation’s gross domestic product.

Department of fisheries divided the coastal belts into 68 fisheries districts. There are 41 districts on the West Coast of Peninsular Malaysia, 18 on the East Coast, 15 in Sarawak and 12 in Sabah. This is to maintain the sustainable fish catches and to avoid conflict of territory among fishermen. Fish catch in Terengganu contributes to almost 40% of the overall total fish catch in peninsular Malaysia. Therefore, this research focuses on marine capture fisheries in Terengganu.

Manmade activities such as pollution, overexploitation and uncontrolled fishing activities are among the factors that contribute to the declining of fish catch. Many of fish stocks in Malaysia are facing an extremely high level of exploitation. Overfishing or uncontrolled fish catch will lead to the fish extinction and scientists predict, with the rate of present fish catch, by year 2048 there will be no fish in sea left [1]. If the optimum limit, for sustainable fish catch is known and followed. This would prevent the declining and extinction of fishes.

The surplus production model estimates the maximum sustainable yield which is important in fisheries sector. Parameters in estimating maximum sustainable yield can be estimated using linear regression or Bayesian surplus model. Thus, this study aims to determine the maximum sustainable yield in Terengganu using Bayesian surplus model.
Bayesian analysis is a method that can be used to improve the reliability of stock assessment in data poor situations by having strength from prior information deduced from species with quality data and will provide direct uncertainty parameter estimator that are straightforward and easy to interpret for risk analysis. [2] applied Bayesian statistical framework to estimate surplus production model of seven year available biomass estimates of Japanese spiky sea cucumber and found overfishing of the fish stock.

2. Data
The yearly data for marine fish landing in Terengganu are obtained from the Department of Fisheries (DOF) Malaysia. The data include size of yearly fish catch (tonnes), total fishing effort (number of trips) and catch per unit effort (CPUE) from year 2000 to 2016. In estimating the parameters and estimate the maximum sustainable yield Minitab version 18 and ASPIC software are used.

3. Methodology
Figure 1 shows the flowchart of the difference between the methodology using Bayesian surplus model and linear regression to estimate parameters in determining the maximum sustainable yield (MSY). However, for this research only Bayesian surplus model will be applied.

![Figure 1. The difference between MSY using linear regression and Bayesian Surplus Model.](image)

3.1 Update the existing data
There is a need to forecast the existing data of yearly fish catch as well as effort for year 2017 and 2018 as the data for year 2017 and 2018 are not available. We update the data by applying Holt’s winter method. This method is chosen due to the capability to consider the trend and seasonality factors. Holt-Winter’s method consists of three basic equations which are level component, trend component and seasonality component.
Level Component:

\[ L_t = \alpha \frac{y_t}{S_{t-1}} + (1 - \alpha)(L_{t-1} + b_{t-1}) \]  

(1)

Trend Component:

\[ b_t = \beta (L_t - L_{t-1}) + (1 - \beta)b_{t-1} \]  

(2)

Seasonality Component:

\[ S_t = \gamma \frac{y_t}{L_t} + (1 - \gamma)S_{t-s} \]  

(3)

The m-step-ahead forecast:

\[ F_{t+m} = (L_t + b_t \times m)S_{t-s+m} \]  

(4)

Where:

\( y_t \): Actual value for fish catches in year 2006 to 2016

\( L_t \): Series of level component, comprising of the smoothed values but does not include seasonality

\( b_t \): The trend component estimation

\( S_t \): The seasonality estimation

\( S \): The length of seasonality

\( \alpha \): The level for smoothing constant

\( \beta \): The level for smoothing constant for trend estimation

\( \gamma \): The level for smoothing constant for seasonality estimation

\( m \): The number for step-ahead to be forecast

\( F_{t+m} \): the-step-ahead forecast value for the fish catch in Terengganu for year 2017 and 2018

3.2 Bayesian Surplus Model

Bayesian surplus model comprises of unobserved state variables that are estimate from the observed relative abundance indices catch per unit effort (CPUE) and from catches using observation error likelihood function and prior distributions for model parameters \( \theta \). The observation error likelihood measures the differences between actual and predicted CPUE while the prior distributions represent the relative degree of belief about the possible value of model parameters. Bayesian’s equation is as follows:

\[ \text{Posterior} = \text{Likelihood (CPUE)} \times \text{Prior} \]  

(5)

The value of biomass and annual harvest rate that maximizes biomass production are relevant as biological reference points for maximum sustainable yield (MSY). From the parameters obtained the value of the optimum number of fishing effort (fMSY) can be calculated. The MSY and fMSY are calculated by using Equation 6 and 7, where \( K \) is carrying capacity, \( r \) is growth rate and \( q \) is catchability.

\[ \text{MSY} = \frac{(qK)^2}{4\left(\frac{q^2K}{r}\right)} = \frac{rK}{4} \]  

(6)
\[
\frac{f_{\text{MSY}}}{(qk)^2} = \frac{r}{4\left(q^2k/r\right)} = \frac{r}{2q}
\]  

(7)

Likelihood relies on CPUE data and there are four prior distributions. We simulate 10000 Monte Carlo simulation in order to get best posterior distribution. The summary for prior distributions for estimates maximum sustainable yield are shown in Table 1. B is the upper limit or maximum range while \( \alpha \) is the lower limit or minimum range.

| Parameter  | Distribution | Equation            | Source |
|------------|--------------|---------------------|--------|
| \((B_1/K)\) | Uniform      | \(p(B_1/K) = \frac{1}{\beta - \alpha}\) | [3]    |
| \(q\)      | Uniform      | \(p(q) = \frac{1}{\beta - \alpha}\)          | [4]    |
| MSY        | Uniform      | \(p(\text{MSY}) = \frac{1}{\beta - \alpha}\) | [5]    |
| FMSY       | Uniform      | \(p(\text{FMSY}) = \frac{1}{\beta - \alpha}\) | [5]    |

The joint posterior distribution of the fish production model for Terengganu needs to be sampled to make inferences about the estimate of the model parameters. Given the catch data and \( i \) series of CPUE data, the posterior distribution \( p(\theta | D) \) is proportional to the product of the prior distributions and the CPUE likelihood via Bayes theorem:

- Posterior (K): \( p(\theta | K) \propto p(K) \prod_{i=1}^{N} p(\text{CPUE} | \theta) \)  
- Posterior (q): \( p(\theta | q) \propto p(q) \prod_{i=1}^{N} p(\text{CPUE} | \theta) \)  
- Posterior (r): \( p(\theta | r) \propto p(r) \prod_{i=1}^{N} p(\text{CPUE} | \theta) \)  
- Posterior (MSY): \( p(\theta | \text{MSY}) \propto p(r) \prod_{i=1}^{N} p(\text{CPUE} | \theta) \)  
- Posterior (f(MSY)): \( p(\theta | f(\text{MSY})) \propto p(r) \prod_{i=1}^{N} p(\text{CPUE} | \theta) \)  

4. Results and Discussion

Figure 2 shows that, the fish catches in Terengganu decrease while the fishing effort (fishing trips) increase from year 2000 to 2016. This clearly shows that, there is a problem pertaining to the fish catch in Terengganu.
For Bayesian surplus model, the likelihood and prior are needed in order to estimate the parameter and determine the maximum sustainable yield in Terengganu. The likelihood for catch per unit effort data in Terengganu follow normal distribution \( CPUE \sim N(0.2765, 0.0123) \) that show the mean and variance for likelihood are 0.2765 and 0.0123 respectively.

The prior value for parameter \( B_1/K, q, MSY \) and \( F_{MSY} \) are tabulated in the Table 2. Parameters follow uniform distribution. The lower and upper limit for parameter \( B_1/K \) are 0.1 and 1.0 respectively. The value of \( q \) is 0.0000005 and 0.003. The lower and upper limit for prior parameter \( MSY \) are 95215 tonnes and 121000 tonnes. Lastly, the prior parameter for \( F_{MSY} \) are 0.1 and 1.2 tonnes per trip.

The maximum sustainable yield (MSY) and optimum number of effort at maximum sustainable yield (\( F_{MSY} \)) are estimated using Bayesian surplus approach based on the value form parameter \( K \) and \( q \). Based on the 10000 Monte Carlo simulation using ASPIC software, the results show that, the carrying capacity (\( K \)) for Terengganu sea ground from the year 2000 to 2016 is 361000 tonnes with 0.5 beginning carrying capacity. Meanwhile the fish catchability (\( q \)) is 2.697e-06 tonnes along the year and the fish growth rate (\( r \)) is 1.1091 tonnes along the year. The maximum sustainable yield (MSY) level for the year ahead is 100100 tonnes and optimum number of fishes catch per effort (\( F_{MSY} \)) is 0.5547 tonnes per trip and that would imply only 205700 standard trips per year.

### Table 2. Parameter Estimate.

| Parameter | Distribution |
|-----------|--------------|
| \( B_1/K \) | \( B_1 / K \sim U(0.1 - 1.0) \) |
| \( q \) | \( q \sim U(5.0e-07, 3.0e-03) \) |
| MSY | \( MSY \sim U(95215, 121000) \) |
| \( F_{MSY} \) | \( F(MSY) \sim U(0.1, 1.2) \) |

5. Conclusion
Bayesian surplus model is useful in estimating parameter of maximum sustainable yield at Terengganu. The maximum sustainable yield using Bayesian surplus model is 100100 tonnes that allow for 205700 trips per year. Based on the value of MSY and \( F_{MSY} \), the fish stocks have been overfished from year 2000 to 2008. This is due to the unsustainable fish management during year 2000 to 2008. Thus, fishery administrator needs to take action in order to recover the fish population to ensure the fish catch will be at sustainable par. Bayesian surplus model is useful for providing the probability distribution of the parameters and therefore the uncertainty in each biological reference parameter by using uninformative prior. Parameter estimation using Bayesian surplus model are better when using informative prior.
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