Determination of the status of utilization and effort of little tuna (*Euthynnus affinis*) caught in the North Bolaang-Mongondow waters North Sulawesi

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Abstract. Little tuna (*Euthynnus affinis*) needs to be managed well because even as a renewable natural resources, but can undergo depletion or extinction. One of the approaches in the management of the resources is by modelling. The analysis was performed aiming to get the best estimated for the surplus production model to determine the maximum sustainable yields (MSY), utilization level, and effort level of little tuna. The data of catch and fishing effort little tuna collected from the Marine and Fisheries Service of the North Bolaang-Mongondow Regency and the North Sulawesi Province. Best Surplus Production Model, which is used to assess the potential of little tuna is Schaefer Model. Optimal effort (*EMSY*) of 482 trips per year, with catches of optimal *CMSY* 465.13 tons per year. The effort level for 2017 is 114.10 %, which shows the inefficiency of effort, the utilization level of 125.99 %, showing occur overfishing.

1. Introduction

Little tuna (*Euthynnus affinis*) classified as pelagic fishery resource is important and one of the non-oil export commodity in North Sulawesi. Little tuna in North Sulawesi (including North Bolaang-Mongondow waters) in 2016 reached 30,000 tons per year, with a value of about 100 billion rupiahs [1]. Research on little tuna generally discuss the exploitation in increase production, not much research on the status of utilization (including aspects of sustainability and efficiency) resources. Data on the level of utilization of the fish resources are very important, as it will determine whether the resource use is less than optimal, optimal, or excessive. Excessive utilization of fish resources would threaten its sustainability. By knowing the level of resource utilization on the little tuna, is expected to be done in a planned and sustainable management.

The simplest model of the dynamics of fish populations is Surplus Production Model (SPM), by treating the fish as a single biomass that can not be divided, which is subject to the rules of simple increases and decreases in biomass. This model, commonly used in the assessment of fish stocks using only the data of catch and fishing effort generally available.

This study aims to get the best SPM, as well as knowing how much the result of maximum sustainable yields (MSY), utilization level, and the level of effort of little tuna in the North
Bolaang-Mongondow waters.

2. Materials and Methods

The primary and secondary data of little tuna catching is collected from the North Bolaang-Mongondow waters. Production and fishing effort data collected from the Marine and Fisheries Service of North Bolaang-Mongondow Regency and North Sulawesi Province during years 2008-2017. Data (variables) used for the analysis of the surplus production model is the data of the Catch ($C_t$) per year, fishing effort ($E_t$) per year, and CPUE (Catch per Unit of Effort)

The models estimator who analyzed and evaluated are: Schaefer, Fox, Schnute, Walter-Hilborn, Clarke-Yoshimoto-Pooley (CYP). Based on the results of statistical evaluation (sign suitability of regression coefficient, the value of $R^2$, the validation value, and significance of the regression coefficient of models), we get the “best” as estimator. From the best of model can be calculated CMSY value, utilization level, and the level of effort of little tuna.

The simplest model of the dynamics of fish populations is a surplus production model that treats the fish population as a single biomass that cannot be divided, which is subject to the simple rules of the rise and decline. The production model is dependent on the amount of four kinds, namely: biomass population at a given time $t$ ($B_t$), catches for a certain time $t$ ($C_t$), fishing effort at a certain time $t$ ($E_t$), and the natural growth rate constant ($r$) [2]. This model was first developed by Schaefer, who was initially the same as the form of logistic growth model.

According to Coppola and Pascoe [3], equation surplus consists of several constants that are affected by natural growth, the ability of fishing gear, and carrying capacity. Constants allegedly using models of biological parameter estimators of surplus production equation, namely the model: Equilibrium Schaefer, Schaefer Disequilibrium, Schnute, and Walter-Hilborn. Based on the four models were selected the most appropriate or best fit of the estimation of others.

According to Sparre and Venema [4], formulas surplus production model is valid only if the slope parameter (b) is negative, which means the addition of fishing effort will lead to a decrease in the catch per fishing effort. If the parameter b positive value, then it can not be done estimating the optimum amount of stock and effort, but it can only be concluded that the addition of fishing effort is still possible to increase the catch.

Prediction of optimum fishing effort ($E_{opt}$) and the maximum sustainable catch ($C_{MSY}$) approached the surplus production model. Between the catch per unit of effort (CPUE) and fishing effort can be either linear or exponential relationship [5]. Surplus Production Model consists of two models, namely basic model of Schaefer (linear relationship) and the Gompertz model developed by Fox with forms exponential relationship [5].

The procedures for estimates of surplus production models follows these equations:

Surplus production models first developed by Schaefer, who was initially the same as the form of logistic growth model. The model is as follows:

\[ \frac{dB_t}{dt} = G(B_t) = r B_t \left( 1 - \frac{B_t}{K} \right) \]  

(1)

This equation does not include the effect of the catching, so Schaefer wrote back to:

\[ \frac{dB_t}{dt} = r B_t \left( 1 - \frac{B_t}{K} \right) - C_t \]  

(2)

$K$ is the carrying capacity of the marine environment, and $C_t$ is the catch that can be written as:

\[ C_t = q E_t B_t \]  

(3)
q is catchability, and Et indicates fishing effort. This equation can be written as:

\[
\frac{C_t}{E_t} = q \cdot B_t = \text{CPUE} \tag{4}
\]

From the differential equation (2), the optimum catchment can be calculated at the time \( \frac{dB_t}{dt} = 0 \), also called settlement at the point of balance (equilibrium), in the form of:

\[
r \cdot B_t \left( 1 - \frac{B_t}{K} \right) - C_t = 0, \quad \text{or}
\]

\[
C_t = r \cdot B_t \left( 1 - \frac{B_t}{K} \right) = q \cdot E_t \cdot B_t \tag{5}
\]

From equation (3) and (5), find value of \( B_t \) obtained as follows:

\[
B_t = K \left( 1 - \frac{qE_t}{r} \right) \tag{6}
\]

So that equation (5) becomes:

\[
C_t = q \cdot K \cdot E_t \left( 1 - \frac{qE_t}{r} \right)
\]

\[
= q \cdot K \cdot E_t - \frac{q^2K}{r} \cdot E_t^2 \tag{7}
\]

Equation (7) is simplified further by Schaefer becomes:

\[
\frac{C_t}{E_t} = a - b \cdot E_t, \quad \text{or}
\]

\[
C_t = a \cdot E_t - b \cdot E_t^2 \tag{8}
\]

while the \( a = qK \) and \( b = \frac{q^2K}{r} \)

This linear relationship is used widely for calculating \( C_{\text{MSY}} \) through the determination of the first derivative of \( C_t \) with \( E_t \) to find optimal solutions, both to catch and fishing effort. The first derivative of \( C_t \) to \( E_t \) is:

\[
\frac{dC_t}{dE_t} = a - 2b \cdot E_t, \quad \text{in order to obtain the alleged} \ E_{\text{opt}} \ (\text{optimum fishing effort}) \text{ and } C_{\text{MSY}} \ (\text{maximum sustainable yields}) \text{ respectively:}
\]

\[
E_{\text{opt}} = \frac{a}{2b} = \frac{r}{2q} \tag{9}
\]

by entering the value of \( E_{\text{opt}} \) in equation (8), will be obtained \( C_{\text{MSY}} \) as follows:

\[
C_{\text{MSY}} = a \cdot E_t - b \cdot E_t^2
\]

\[
= a \left( \frac{a}{2b} \right) - b \left( \frac{a}{2b} \right)^2
\]
by substituting \( a = qK \) and \( b = \frac{q^2K}{r} \) will be obtained,

\[
CMSY = \frac{a^2}{4b} = \frac{q^2K^2}{4q^2K/r} = \frac{rK}{4} \tag{10}
\]

The values of \( a \) and \( b \) are estimated by the least squares method approach that is commonly used to estimate the coefficient of a simple regression equation. Furthermore, by including the value of \( E_{opt} \) in equation (6) is obtained optimum biomass (\( B_{MSY} \)) as follows:

\[
B_{MSY} = K - \frac{Kq}{r}E_{opt} = K - \frac{Kq}{r} \left( \frac{r}{2q} \right) = K - \frac{K}{2} = \frac{K}{2} \tag{11}
\]

The values of the parameter \( q, K, \) and \( r \) can be calculated using the Fox algorithm, as referenced in Sularso [6], as follows:

\[
q_t = \ln \left[ \left( \frac{zU_t^{-1} + \frac{1}{b}}{zU_{t+1}^{-1} + \frac{1}{b}} \right) \right] / (z) \tag{12}
\]

where \( z = \frac{a}{b} / E^*, \ E^* = \frac{(E_t + E_{t+1})}{2}, \ U_t = \frac{C_t}{E_t} \) and the value of \( q \) is the geometric mean of the value of \( q_t \). From the values of \( a, b, \) and \( q \), can then be calculated values of \( K \) and \( r \).

Model of Fox has several characteristics that are different from the model Schaefer, that it biomass growth following the Gompertz growth model [7]. The relation of CPUE with effort (\( E \)) follows a negative exponential pattern:

\[
C_t = E_t \cdot \exp(a - bE_t) \tag{13}
\]

Efforts optimum is obtained by equating the first derivative of \( C_t \) to \( E_t \) equal to zero and find:

\[
E_{opt} = \frac{1}{b} \tag{14}
\]

The maximum sustainable yields of catch (\( C_{MSY} \)) is obtained by inserting the value of the optimum effort into equation (13), and obtained:

\[
C_{MSY} = \frac{1}{b} e^{b-1} \tag{15}
\]

Model of Schnute [8], suggests another version of the surplus production model is dynamic and deterministic. Schnute method is considered as a modification of the model in the form of discrete Schaefer (Roff, 1983, referred by Tinungki) [9],
\[
\ln \left( \frac{U_{t+1}}{U_t} \right) = r - \frac{r}{qK} \left( \frac{U_t + U_{t+1}}{2} \right) - q \left( \frac{E_t + E_{t+1}}{2} \right)
\]

\[
= a - b \left( \frac{U_t + U_{t+1}}{2} \right) - c \left( \frac{E_t + E_{t+1}}{2} \right)
\]

(16)

where \( a = r \), \( b = \frac{r}{qK} \), and \( c = q \) is the regression coefficient estimators.

Walter and Hilborn (1976) referred by Tinungki [9], to develop other types of surplus production model, known as the regression model. Walter - Hilborn Model, using a simple differential equation, by the following equation:

\[
\frac{U_{t+1}}{U_t} - 1 = r - \frac{r}{Kq} U_t - q E_t
\]

\[
= a - b U_t - c E_t
\]

(17)

where \( a = r \), \( b = \frac{r}{Kq} \), and \( c = q \) is the regression coefficient estimators.

Estimation of biological parameters for the surplus production model can also be done through estimation techniques proposed by Clarke, Yoshimoto, and Pooley (CYP) [9, 10]. The parameters which allegedly is \( r \), \( K \), and \( q \), the model is expressed as follows:

\[
\ln(U_{t+1}) = \left( \frac{2r}{2+r} \right) \ln(qK) + \frac{2-r}{2+r} \ln(U_t) - q \left( \frac{E_t + E_{t+1}}{2+r} \right)
\]

where : \( a' = \frac{2r}{2+r} \), \( a = a' \ln(qK) \), \( b = \frac{2-r}{2+r} \), \( c = \frac{q}{2+r} \)

thus equation (18) can be written in the form:

\[
\ln(U_{t+1}) = a' \ln(qK) + b \ln(U_t) - c (E_t + E_{t+1})
\]

\[
= a + b \ln(U_t) - c (E_t + E_{t+1})
\]

(19)

3. Results and Discussion

Catches of little tuna fisheries in the North Bolaang-Mongondow waters fluctuate from year to year. Data catching in 2008-2017, are presented in Table 1.

From the analysis of regression, equation for Schaefer Model : \( \frac{C_t}{E_t} = 1.929 - 0.002 E_t \) with a coefficient of determination \( (R^2) = 0.734 \) and a significance level of \( p < 0.05 \). Thus, a production model estimator catches Schaefer model according to the equation (8) is: \( C_t = 1.929 E_t - 0.002 E_t^2 \).

From the results of the regression analysis for Fox Model:

\[ \ln \left( \frac{C_t}{E_t} \right) = 0.733 - 0.001 E_t \] with \( R^2 = 0.731 \) \( (p < 0.05) \). Estimates of catches corresponding to the
model Fox equation (13):
\[ C_t = E_t \cdot e^{(0.733 - 0.001 E_t)} \]

Table 1. Total catch, fishing efforts, and CPUE (Catch per Unit of Efforts) of Little tuna in North Bolaang-Mongondow waters 2008-2017

| Years | Catch (ton), C_t | Effort (trip), E_t | CPUE = \( \frac{C_t}{E_t} \) |
|-------|-----------------|--------------------|-------------------|
| 2008  | 401.0           | 240                | 1.6708            |
| 2009  | 391.0           | 300                | 1.3033            |
| 2010  | 457.0           | 480                | 0.9521            |
| 2011  | 400.9           | 400                | 1.0022            |
| 2012  | 541.6           | 484                | 1.1190            |
| 2013  | 531.0           | 528                | 1.0057            |
| 2014  | 524.7           | 527                | 0.9956            |
| 2015  | 471.0           | 480                | 0.9813            |
| 2016  | 509.0           | 525                | 0.9695            |
| 2017  | 586.0           | 550                | 1.0655            |
| Mean  | **481.320**     | **451.400**        | **1.1065**        |

Source: Calculated from the Marine and Fisheries Service and Landing Station of Fish in North Bolaang-Mongondow

For Schnute model according to equation (16), obtained regression equation:
\[
\ln\left(\frac{U_{t+1}}{U_t}\right) = 0.055 - 0.337 \left(\frac{U_t + U_{t+1}}{2}\right) + 0.01 \left(\frac{E_t + E_{t+1}}{2}\right)
\]
with \( R^2 = 0.457 \), and all the regression coefficient was significant (\( p > 0.05 \)).

In Walter-Hilborn Model using equation (17) derived regression equation:
\[
\frac{U_{t+1}}{U_t} - 1 = 1.009 - 0.651 U_t - 0.001 E_t
\]
With \( R^2 = 0.831 \) and not all regression coefficients were significant (\( p < 0.05 \)). In the regression equation CYP Model, according to equation (19):
\[
\ln(U_{t+1}) = 0.325 + 0.074 \ln(U_t) - 0.000320(E_t + E_{t+1})
\]
with \( R^2 = 0.464 \), and the regression coefficient are not significant (\( p > 0.05 \)). The results of calculations for validation surplus production model of 5 models is presented is summarized in Table 2.

Table 2. Results of the surplus production model validation

| Model     | Schaefer | Fox | Schnute | Walter-Hilborn | CYP |
|-----------|----------|-----|---------|----------------|-----|
| Sign Suitability | Appropriate | Appropriate | Not Appropriate | Appropriate | Appropriate |
| R² Value  | 0.734    | 0.731 | 0.457   | 0.831          | 0.464 |
| Validation Value | **0.1019** | 0.2258 | 13.6514 | 0.2214          | 0.9871 |
| Significance Coefficient | Significant | Significant | Not Significant | Not all significant | Not Significant |
From the results of the calculations in Table 2, it appears that the most appropriate is Schaefer model with the \( R^2 \) value is quite large (\( R^2 = 0.734 \)) and validation (residual value) is smallest. Schaefer model obtained values of \( a = 1.929 \) and \( b = 0.002 \), with equation (9) and (10) can be calculated optimum value of Effort \( (E_{opt}) \) and the maximum sustainable catch \( (C_{MSY}) \) as follows:

\[
E_{opt} = \frac{a}{2b} = \frac{1.929}{2(0.002)} = 482.25 \approx 482 \text{ trips per year.}
\]

\[
C_{MSY} = \frac{a^2}{4b} = \frac{1.929^2}{4(0.002)} = 465.13 \text{ tons per year.}
\]

This means that in order to preserve the bonito fisheries resources technically and biologically, in a year the number of units should not exceed 482 trips. To preserve the Little tuna resources in the waters North Bolaang-Mongondow, the maximum of fish that can be caught at 465.13 tons per year. Furthermore, from the value of \( E_{opt} \) and \( C_{MSY} \) can be calculated fishing effort levels and utilization level of bonito for a particular year for example in 2017, as follows:

The level of effort in 2017 = \( \frac{E_{2017}}{E_{opt}} \times 100\% \)

\[
= \frac{550}{482} \times 100\% = 114.10 \%
\]

The utilization level in 2017 = \( \frac{C_{2017}}{C_{MSY}} \times 100\% \)

\[
= \frac{586.0}{465.13} \times 100\% = 125.99 \%.
\]

From the calculation, it turns out Little tuna fishing effort at the North Bolaang-Mongondow waters in 2017, greater than the maximum sustainable level of effort. This shows that fishing effort is not efficient. The utilization level for the year 2017, is more than optimum level, its mean a sign of overfishing (catch-over). The same result of Little tuna fishing effort and utilization level at the Talaud waters shows not efficient and overfishing [11], at Manado waters [12], also at Bitung waters [13].

This study describes the use of some statistical criteria in selecting the best surplus production model. By applying some statistical criteria in selecting a surplus production model, will obtain better results. Researchers in the field of fisheries get guidelines for setting selection criteria for surplus production models, as well as avoiding the direct application of one model in analyzing the surplus production model in a waters.

4. Conclusions and Recommendations

4.1 Conclusions

1. The surplus production model that can be used to examine the catch of little tuna in the North Bolaang-Mongondow waters is Schaefer model, by the equation: \( C_t = 1.929 E_t - 0.002 E_t^2 \).

2. The maximum sustainable yield of little tuna \( C_{MSY} \) is 465.13 tons per year, obtained at the of fishing effort \( E_{MSY} \) 482 trips per year. For the year 2017 the amount of 125.99 % utilization level is a sign of overfishing, with the level effort 114.10 % indicating inefficiencies in fishing effort.

4.2 Recommendations

1. In applying surplus production model in a waters location, not only directly using one particular model, but should use some of the models are chosen base on statistical criteria.
These criteria involve, among others: suitability sign of the coefficient of models, coefficient of determination ($R^2$), the value of validation, and the significance of the regression coefficients.

2. There are indications occur overfishing and the presence of the inefficiency of fishing effort of little tuna in the North Bolaang-Mongondow waters, recommended immediate supervision by competent institutions to handle this issue.

Appendix

Appendix I. Regression analysis of Surplus Production Model of little tuna data in North Bolaang-Mongondow waters

1. Model Schaefer

| Model Summary |  |
|---------------|---|
| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
| 1 | .857\(a\) | .734 | .701 | .1224453 |
| a. Predictors: (Constant), Et |

| ANOVA |  |
|-------|---|
| Model | Sum of Squares | df | Mean Square | F | Sig. |
| Regression | .331 | 1 | .331 | 22.058 | .002\(b\) |
| Residual | .120 | 8 | .015 |  |
| Total | .451 | 9 | |  |
| a. Dependent Variable: Ct_per_Et |
| b. Predictors: (Constant), Et |

| Coefficients |  |
|--------------|---|
| Model | Unstandardized Coefficients | Standardized Coefficients | T | Sig. |
| (Constant) | 1.929 | .179 | | |
| Et | -.002 | .000 | -.857 | -4.697 | .002 |
| a. Dependent Variable: Ct_per_Et |

2. Model Fox

| Model Summary |  |
|---------------|---|
| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
| 1 | .855\(a\) | .731 | .697 | .0970864 |
| a. Predictors: (Constant), Et |

| ANOVA |  |
|-------|---|
| Model | Sum of Squares | df | Mean Square | F | Sig. |
| Regression | .205 | 1 | .205 | 21.748 | .002\(b\) |
| Residual | .075 | 8 | .009 |  |
| Total | .280 | 9 | |  |
| a. Dependent Variable: Ln_CtperEt |
| b. Predictors: (Constant), Et |

| Coefficients |  |
|--------------|---|
### 3. Model Schnute

| Model | Unstandardized Coefficients | Standardized Coefficients | t | Sig. |
|-------|-----------------------------|---------------------------|---|------|
|       | B | Std. Error | Beta |     |     |
| (Constant) | .733 | .142 |     | 5.157 | .001 |
| Et | -.001 | .000 | -.855 | -4.663 | .002 |

a. Dependent Variable: Ln_CtperEt

#### Model Summary

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|-------|---|----------|-------------------|---------------------------|
| 1 | .676\textsuperscript{a} | .457 | .276 | .1253970 |

a. Predictors: (Constant), EttambahsatutambatEtperdua, UttambahsatutambahUtperdua

#### ANOVA\textsuperscript{a}

| Model | Sum of Squares | df | Mean Square | F | Sig. |
|-------|----------------|----|-------------|---|------|
| Regression | .079 | 2 | .039 | 2.522 | .160\textsuperscript{b} |
| Residual | .094 | 6 | .016 |     |     |
| Total | .174 | 8 |     |     |     |

a. Dependent Variable: LnUttambahsatuperUt

b. Predictors: (Constant), EttambahsatutambahEtperdua, UttambahsatutambahUtperdua

#### Coefficients\textsuperscript{a}

| Model | Unstandardized Coefficients | Standardized Coefficients | t | Sig. |
|-------|-----------------------------|---------------------------|---|------|
|       | B | Std. Error | Beta |     |     |
| (Constant) | .055 | 1.130 |     | .049 | .963 |
| UttambahsatutambahUtperdua | -.337 | .597 | -.369 | -.564 | .593 |
| EttambahsatutambahEtperdua | .001 | .001 | .326 | .498 | .636 |

a. Dependent Variable: LnUttambahsatuperUt

### 4. Model Walter-Hilborn

#### Model Summary

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|-------|---|----------|-------------------|---------------------------|
| 1 | .912\textsuperscript{a} | .831 | .775 | .0498222 |

a. Predictors: (Constant), Et, Ct_per_Et

#### ANOVA\textsuperscript{a}

| Model | Sum of Squares | df | Mean Square | F | Sig. |
|-------|----------------|----|-------------|---|------|
| Regression | .073 | 2 | .037 | 14.766 | .005\textsuperscript{b} |
| Residual | .015 | 6 | .002 |     |     |
| Total | .088 | 8 |     |     |     |

a. Dependent Variable: UttambahsatuperUtkurangsatu

b. Predictors: (Constant), Et, Ct_per_Et

#### Coefficients\textsuperscript{a}

| Model | Unstandardized Coefficients | Standardized Coefficients | t | Sig. |
|-------|-----------------------------|---------------------------|---|------|
|       | B | Std. Error | Beta |     |     |
| (Constant) | .055 | 1.130 |     | .049 | .963 |
| UttambahsatutambahUtperdua | -.337 | .597 | -.369 | -.564 | .593 |
| EttambahsatutambahEtperdua | .001 | .001 | .326 | .498 | .636 |

a. Dependent Variable: UttambahsatuperUt
### Model Summary

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|-------|---|----------|------------------|---------------------------|
| 1     | .681* | .464 | .285 | .0831340 |

*a. Predictors: (Constant), EttambahEttambahsatu, Ln_CtperEt*

### ANOVA

| Model | Sum of Squares | df | Mean Square | F | Sig. |
|-------|----------------|----|-------------|---|------|
| Regression | .036 | 2 | .018 | 2.597 | .154* |
| Residual | .041 | 6 | .007 | | |
| Total | .077 | 8 | | | |

*a. Dependent Variable: LnUttambahsatu*

*b. Predictors: (Constant), EttambahEttambahsatu, Ln_CtperEt*

### Coefficients

| Model | Unstandardized Coefficients | Standardized Coefficients | t | Sig. |
|-------|-----------------------------|---------------------------|---|------|
| (Constant) | .325 | .348 | .932 | .387 |
| 1 | Ln_CtperEt | .074 | .321 | .141 | .232 | .824 |
| EttambahEttambahsatu | .000 | .000 | -.554 | -.909 | .399 |

*a. Dependent Variable: LnUttambahsatu*

### Validation of Surplus Production Model of little tuna

**Schaefer Model**

\[ \hat{C}_t = 1.929E_t - 0.002E_t^2 \]

**Fox Model**

\[ \hat{C}_t = E_t e^{0.733-0.001E_t} \]
3. Schnute Model: 
\[ \hat{Y} = a - b X_1 - c X_2 = 0.055 - 0.337 X_1 + 0.001 X_2 \]
\[ r = a = 0.055 \quad q = c = 0.01 \quad b = \frac{r}{Kq} = 0.337 \]
\[ K = \frac{r}{bq} = \frac{0.055}{(0.337)(0.01)} = 16.3204 \]
\[ \hat{C}_r = Kq E_i - \frac{Kq^2}{r} E_i^2 = 0.1632 E_i - 0.0297 E_i^2 \]

4. Walter – Hilborn Model: 
\[ \hat{Y} = a - b X_1 - c X_2 = 1.009 - 0.651 X_1 - 0.001 X_2 \]
\[ r = a = 1.009 \quad q = c = 0.001 \quad b = \frac{r}{Kq} = 0.651 \]
\[ K = \frac{r}{bq} = \frac{1.009}{(0.651)(0.001)} = 1549.9232 \]
\[ \hat{C}_r = Kq E_i - \frac{Kq^2}{r} E_i^2 = 1.5499 E_i - 0.001636 E_i^2 \]

5. CYP Model: 
\[ \hat{Y} = a + b X_1 - c X_2 = 0.325 + 0.074 X_1 - 0.000320 X_2 \]
\[ r = \frac{2(1-b)}{1+b} = 2(1-0.074) = 1.7244 \quad q = c(2-r) = 0.000320(2-1.7244) = 0.00008819 \]
\[ Q = \frac{a(2+r)}{2r} = \frac{0.325(2+1.7244)}{2(1.7244)} = 0.3509 \]
\[ K = \frac{e^Q}{q} = \frac{e^{0.3509}}{0.00008819} = 161.0500 \]
\[ \hat{C}_r = Kq E_i - \frac{Kq^2}{r} E_i^2 = 0.0142 E_i - 0.000000726 E_i^2 \]

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